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Performance Evaluation of a Game Theoretical routing protocol over Mobile Ad Hoc Networks

by

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> “Productivity is never an accident. It is always the result of a commitment to excellence, intelligent planning, and focused effort.”
>
> *Paul J. Meyer*
>
> American entrepreneur and author

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Carpe diem. Seize the day. Opportunities, if they appear, they are to be taken, not to miss them. When I started my Master studies I never imagined how rewarding and illustrative the execution of a thesis was. You have the opportunity of deeply learning about what you are really interested in, and you discover yourself working in a collaborative environment together with your advisor and research partners; Fully advisable.

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Abstract

In recent years, the number of mobile and portable devices which are capable to have wireless communications has increased, these mobile nodes connected by wireless link may form a self-configured network to constitute a Mobile Ad-Hoc Network (MANET). Wireless technology has led to development of new communication technology and multimedia services. Due to the continued growth of the mobile users, the demand of multimedia services such as video streaming has increased.

Nodes can act as a host or router to forward data from one node to another node in a network which is not reachable by one hop. As they can move freely through the network, it is common to have link breakage, so alternative path should be provided quickly. Furthermore, more stable and reliable paths must be available instead of one path. There are many type of video coding technique for MANET, which one of the best technique used is MPEG-2 VBR that it has a capability of using a proper multipath routing in order to improve distribution of video streams over the paths. Thus for receiving to the best performance using a technique called g-MMDSR (game theoretic- Multipath Multimedia Dynamic Source Routing) in order to select the paths dynamically for sending video by using the game theory approach. The g-MMDSR is an extension of a-MMDSR (adaptive Multimedia Multipath Dynamic Source Routing) technique that includes a game theoretic algorithm in the multipath routing scheme in order to share resources among competing nodes.

Our scheme is used to improve the performance of the framework and experience of the end user by sending the most important video frames from one of the two best available paths according to certain probability. In this way we need to examine P value as a fixed and variable to reach the best outcomes, where the number of mobility of the nodes and interfering traffic is too much. This method has designed for MANET network but it capable to use it over the VANET network as well. The result of simulation have demonstrated the benefit of using the game theory technique in different situation over none game theory and also the benefit of variable P value over fixed P value in game theory.

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Glossary

ADAS	Advanced Driver Assistance Services
ADV	Adaptive Distance Vector
a-MMDSR	Adaptive- Multimedia Multipath Dynamic Source Routing protocol
AODV	Ad hoc On-demand Distance Vector
ARQ	Automatic Repeat Request
ARS	Automatic Route Shortening
BW	Bandwidth
CBR	Constant Bit Rate
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing protocol
EWMA	Exponentially Weighted Moving Average
FE	Flowstate Extension
FEC	Forward Error Correction
FPL	Fraction Packet Loss
g-MMDSR	game theoretic- Multimedia Multipath Dynamic Source Routing protocol
GoP	Group of Pictures
HM	Hello Messages
HMR	Hello Message Reply
IP	Internet Protocol
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
MAC	Medium Access Control
MANET	Mobile Ad Hoc Network
MM	Mobility Metric
MMDSR	Multipath Multimedia Dynamic Source Routing Protocol
MOS	Mean Opinion Score

MPEG	Moving Picture Experts Group
MPLS	Multi Protocol Labeling Switching
MSE	Mean Square Error
NS2	Network Simulator 2
OBU	On Board Units
OSI	Open Systems Interconnection
PDV	Packet Delay Variation
PM	Probe Message
PMR	Probe Message Reply
PSNR	Peak Signal to Noise Ratio
QoS	Quality of Service
RERR	Route Error
RM	Reliability Metric
RMSE	Root Mean Square Error
RREP	Route Reply
RREQ	Route Request
RSU	Road Side Units
RSVP	Resource Reservation Protocol
RTCP	Real Time Control Protocol
RTP	Real-Time Transport Protocol
SBM	Subnet Bandwidth Management
SINR	Signal to Interference plus Noise Ratio
s-MMDSR	Static Multimedia Multipath Dynamic Source Routing protocol
SNR	Signal to Noise Ratio
TCL	Tool Command Language
TCP	Transmission Control Protocol
TTL	Time To Live
UDP	User Datagram Protocol

V2V	Vehicle 2 Vehicle
VANET	Vehicular Ad Hoc Network
VBR	Variable Bit Rate
VOIP	Voice Over IP
WLAN	Wireless Local Area Network
WSN	Wireless Sensor node
ZRP	Zone Routing Protocol

1. Introduction

1.1. Game theory concept

Game theory is useful for acting and predicting behavior of others and designing systems with multiple participants. Also games are strategic interaction between rational entity and players. Game normally defines by the players, a set of strategies for each player and a preference relation for each player over possible outcomes. A player gives the set of strategy or action for every player in the game. In the game theory, there is a basic and crucial assumption of the rationality that says every player is the utility optimizer or maximizer, in order to minimizing the cost or maximizing the utility and player has a payoff function for optimizing the payoff function.

There are three types of games, which called extensive, cooperative and repeated games. In the extensive form of games the players take an action in turns rather than simultaneously as in normal form games. In cooperative games that players do have individual interest but they coordinate their action to achieve particular goals, so called that cooperative or coalitional and the last one is repeated that can take any game such as cooperative and non-cooperative and can repeat it and player probably would not mind to get allow outcome some particular steps but she/he cares about expected payoff of whole around the games so it will effect to the strategic in each rounds, so this game indeed require different analysis which is more complicated.

1.2. Layout of work

A Mobile Ad hoc Network (MANET) is set of mobile nodes that comes together as needed, not necessarily with any support from the existing network infrastructure or any other kind of fixed stations. The network topology may dynamically change in an unpredictable manner because nodes are free to move [1]. As transmission range of wireless network interfaces is limited, in some cases forwarding hosts are needed. Therefore each node itself acts as a router for forwarding and receiving packets to/from others nodes. Nodes are free to move and the capacity of their battery is limited, which makes MANETs suffer from frequent changes in network topology. As a result MANET should adopt dynamically to be able to maintain on-going communications in spite of these changes [2].

During the last decade, Mobile Ad Hoc Network had a rapid growth of research interest. The infrastructureless and the dynamic nature of these networks demands new set of networking strategies to be implemented in order to provide efficient end to end communication. This, along with diverse application of these networks in many different scenarios such as battlefield, disaster recovery, emergency rescues and exploration missions, has seen MANETs being researched by many different organizations and institutes [3] where video streaming service are likely to be used.

For obtaining QoS (Quality of Service) in multimedia services on MANET, it is not sufficient to provide a basic routing functionality. Other aspects should also be taken into consideration such as bandwidth constraints due generally to share media, dynamic topology since MNs (Mobile Nodes) are mobile and the topology may change and power consumption due to limited the batteries, make the QoS provision over these networks a really challenging target. These issues make self configuration and system adaptation a matter of major importance in MANETs. Therefore is better to create a framework that configuration parameters adapt according to the dynamic environment, instead of using fixed network configuration parameters. It is desirable to improve a dynamic scheme according cross layer design that consider different adjustable parameters of the protocol stack because QoS of network depend to the coordinated efforts from all layer instead of single network layer.

This work is mainly focused on improve of a QoS-aware self-configured dynamic framework that is able to offer video streaming service over MANETs, which g-MMDSR (game theoretic-Multimedia Multipath Dynamic Source Routing) is a cross layer multipath routing protocol.

1.3. Related Work

There are many QoS frameworks proposed for MANETS, which the first generation of routing protocol was based on the number hops and the next generation was based on the link quality, route lifetime and available bandwidth. In this network, routing protocol must be able to select the best available paths among the mobile nodes, since many approaches are proposed for MANETs like mobility aware routing protocol, which mobiles nodes are grouped into classes according to the rate and different routing techniques for each mobility class [4]. Use multipath routing for transmitting video over Ad hoc networks, where multiple video coding uses to transfer video through several paths [5]. Improving routing algorithm in order to decrease congestion and increase the video quality for distribute traffic through multiple paths [6].

There are two important issues related to game theory over mobile Ad Hoc network, each issue concern about some approaches which are listed below.

First issue is used to encourage nodes to cooperate with others nodes by 1) applying a multi-stage dynamic pricing game, which including forwarding incentives for the relaying nodes by determine the value of their packet forwarding services in the best possible way based on the auction rules [7]. 2) Applying a solution for a game theory when there is channel noise to enforce collaboration in Ad Hoc networks [8]. 3) Applying solution like Nash Equilibrium for classic game theory to solve the problem of collusion resistance when there is cheat between some nodes. In this case these nodes can use more utilities from others nodes, since performance of the system is decreased [9].

Second issue is used for applying game theory in order to obtain a QoS-aware framework by 1) applying technique to allows nodes to choice the route in case of the traffic equilibrium network. According to this technique, nodes take decision for routing the frames in order to minimize the delay regarding to hierarchical routing game [10]. 2) Using techniques for those Mobile Ad Hoc network nodes that have less mobility and stable by extracting the core and subset nodes in order to find better paths in the extracted core nodes based on the QoS-aware routing protocol [11]. 3) Providing multi leader/follower game to overcome the problem of dynamic capacity allocation and QoS routing, which in this approach the followers playing according to the strategies of leaders, since leaders must decrease the congestion of the link and the network users by splitting traffic among multiple links [12].

In this work we used a g-MMDSR (game theoretic-Multipath Multimedia Dynamic Source Routing), a cross layer multipath routing protocol to improve the end to end performance of multimedia services over IEEE 802.11e. This is suitable for video streaming services to achieve dynamic selection of the forwarding paths. Also it is able to self-configure dynamically depending on the state of the network. The multipath routing scheme is improved by game theoretic approach to share resource among competing nodes. This collaboration seek to enhance the overall performance of the service by providing a solution to give certain levels of QoS to the users involved in a multimedia service over MANETs.

There are two different versions proposed and simulated for this framework. The implementation of this work is done in the open source simulator NS2 to let us test our methods, algorithms and routing schemes.

1.4. Dissertation structure

This thesis is organized as follows. In chapter 2, we study about wireless Ad Hoc networks IEEE 802.11 and different types of this network and routing Protocol. In chapter 3, the video streaming services over MANETs are explained. The main performance metrics and most important technique used to improve the performance of video-streaming services are summarized. In the chapter 4, we explained about the framework of the work, The Multipath multimedia Dynamic Source routing Protocol (MMDSR), which present the multipath routing scheme, MMDSR operation and control packets, QoS parameters and path classification. Also, we give brief explanation about two previous methods of multipath technique (s-MMDSR and a-MMDSR).

In chapter 5, we present the last version of MMDSR, called game theory technique (g-MMDSR), which is explained as our framework applies a new multipath routing technique to share resource among competing nodes using a non-cooperative game. In chapter 6, we present a summary of our simulation, simulation result and what we have done in this work. Finally, the last chapter outlines the main conclusions and later gives a proposal for future lines of work we aim to follow in the future.

2. Wireless Ad Hoc Networks IEEE 802.11

The history of wireless ad hoc networks is backed to the Defense Advances Research Project Agency (DAPRPA) Packet Radio Network (PRNet), which evolved into the survivable adaptive radio networks (SURAD) program [13]. Ad hoc networks have played an important role in military applications and related research efforts. Recent years have seen a new spate of industrial and commercial applications for wireless ad hoc networks, as viable communication equipment and portable computers become more compact and available. Wireless network provide to users of mobile ubiquitous computing capability and information access regardless of the users location.

A Wireless ad hoc network is a decentralized type of wireless network. The network is ad hoc because it does not depend on pre-existing infrastructure. In ad hoc network, each node participates in routing by forwarding data to other nodes and then based on the network connectivity takes decision which nodes should forward data. An ad hoc network refers to set of networks where all devices are free to move and have same situation to associate with other ad hoc network devices in link range. Normally ad hoc network refer to mode of operation of IEEE 802.11 wireless networks, which it is a set of standards for implementing wireless local area network (WLAN).

2.1. Wireless Sensor Networks (WSN)

A wireless sensor network is a collection of distributed sensors nodes across a geographical area. It was developed and motivated by military applications such as battlefield surveillance and is now used in a variety of physical phenomena of interest. Wireless sensor networks are used for monitoring real world physical parameters such as temperature, humidity, motion, pressure, sound, etc. in the form understandable by the users. It consist of a transducer to sense a given physical quantity with a predefined precision, an embedded processor for local processing, small memory unit for storage and a wireless transceiver to transmit or receive data. A WSN can be small as a two node network or large as a ten million nodes network. The actual network size will depend on each particular application and deployment [14].

In many applications the nodes may only obtain their power from a battery. Since the network deployment is easy and independent of power supply availability. However replacing the battery may not be practical or even possible. In consequence, energy conversation is a primary goal in WSNs design, as the node will only operate before battery depletion. The most attractive feature of wireless sensor network is their autonomy, when deployed the filed the microprocessor automatically initializes communication with every other node in range, creating an ad hoc mesh network for relaying information to and from the gateway node .The main operation in a sensor network is data forwarding from the sensors to the sink and data aggregation before forwarding data to the sink.

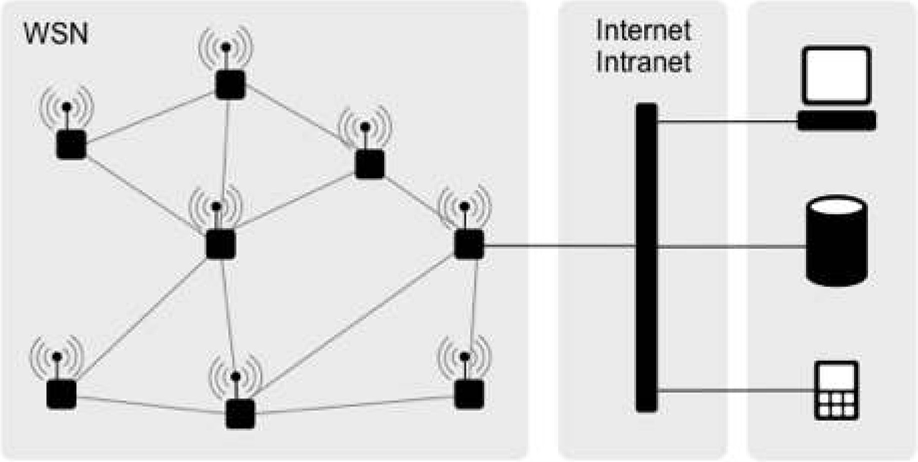


Figure 1 Architecture of a WSN

The main applications areas for WSNs are:

Environmental monitoring: this is a classical application of WSNs. The sensors nodes are spread in a certain area such as forest, mountain, urban area, sea, etc. to monitor the parameters of that area, such as flood detection, temperature, humidity, bacterial levels of waters, air pollution, etc.

Home and Building monitoring: this type of sensors put the users in ease and comfort to monitor the activities performed in a smart home and building like light and climate control, security and safety, automatic plant watering and pet feeding, size area arranging.

Healthcare monitoring: it can be used to avoid cabling around the patient, allows periodically report parameters of patient body, e.g. blood pressure, temperature and heart rate [15], also it can be used to report location of patient and remotely care for those who have disability or elder.

Industrial monitoring and controlling: it can be used to monitoring operation that currently done manually or not, control of warehouses by installing sensors on the product to track their movement and also it provide facility for monitoring harsh industrial environment and alarming to the worker.

Military and battlefield monitoring: can be used by military for number of purposes such as monitoring or tracking the enemies, force protection and detect enemy intrusion, Aerostat acoustic payload for transient detection, solider detection and tracking.

Disaster recovery: Novel sensor network architecture has been proposed in [16] could be useful for major disasters including earthquakes, storms, floods, fires and terrorist attacks. The sensor nodes are deployed randomly at homes, offices, and other places prior to the disaster and data collecting nodes communicate with database server for a given sub, which are linked to a central database for continuous update.

Urban monitoring and controlling: WSNs used for urban environment for many applications such as traffic monitoring to prevent jam traffic in the street by measuring vehicle traffic and alert to driver for changing route, parking operation (e.g. smart parking) and payment on the street, lighting in city for people movement and security, etc.

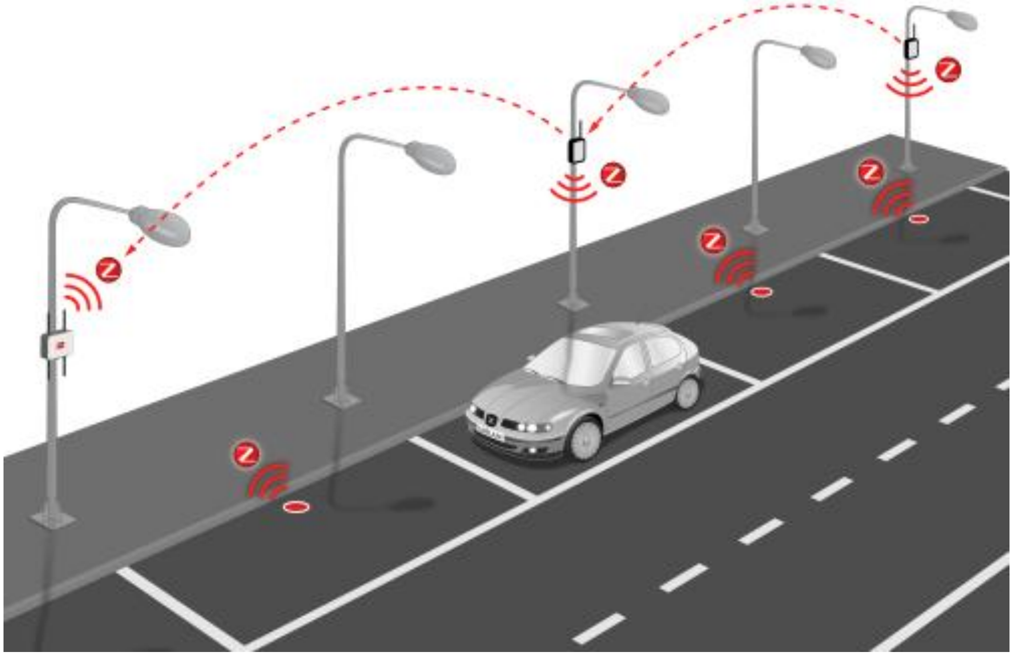


Figure 2 Smart Parking

Provide accurate information on available parking spaces

2.2. Mobile Ad Hoc Networks (MANETs)

During the last years, MANETs have received much attention from research community. Consequently, important technical advances have risen for this network. Recently these multi-hop networks are envisioned as an important type of next generation network access, which the demand of multimedia services is increased by end users [18]. The Quality of Service (QoS) Provision is required for these multimedia services. Special characteristics of MANETs, such as mobility, dynamic topologies, energy constrained, limited bandwidth and lack of centralized infrastructure make the QoS provision a really challenging target over these networks. So the major important issues in MANETs are self-configuration and system adaptation. In addition, since the QoS provided by a network does not depend on any single network layer but on the coordinated efforts from all layers, it is really advisable to develop dynamic solutions based on cross layer approaches able to take into account different technical specifications of the protocol stack. The main characteristics faced in a MANETs are:

Dynamic Topologies: Nodes are free to move arbitrarily with different speeds, thus the network topology may change randomly at unpredictable times. MANET networks may adopt dynamically to the traffic as well as to the movement patterns and the propagation conditions.

Energy Constrained Operation: In an ad hoc network, nodes are fed by limited batteries, so energy consumption is an important issue to be consider. For these nodes, the most important system design optimization criteria may be energy conservation.

Limited Bandwidth: Wireless link continue to have significantly lower capacity than infrastructure networks. In addition, the realized throughput of wireless communications after accounting for the effects of multiple access, fading, noise and interference conditions, etc., is often much less than maximum transmission rate of radio.

Security Threats: Mobile wireless networks are generally more tending to physical security threats than fixed cable networks. The increased possibility of eavesdropping, spoofing and minimization of denial of service type attacks should be carefully considered.

Figure 3 Wireless Mobile Ad Hoc Network

2.2.1. Challenging in MANETs

Almost most of network aspect has been explored in some level of detail, although no ultimate resolution to any of the problems is found yet and there are already many open issues for research and significant contributions. Hence, MANETs environments has to overcome certain issues of limitation and inefficiency. Here, we are mention to some issues.

Efficiency: The one of most important objectives of MANET routing protocol is to maximize energy efficiency in order to improve the performance of the network, since nodes in MANET depend on limited energy resource. It is advisable to discover and maintain routes at the same speed the network changes due to its inherent dynamism. This would save battery energy as well.

Routing: It is clear that routing in MANETs is completely different from traditional routing found on infrastructure networks. Routing in MANET depends on many factors such as selection of routers, topology, initiation of request, unreliability of wireless and resource limitations. The low resource availability in this network demands efficient utilization and hence the motivation for optimal routing in ad hoc networks. One of major challenge in this network concern with a node that at least needs to know the reachability information to its neighbours for determinate a packet route, while the network topology can change quite often in a mobile ad hoc network [19]. In addition, when the number of nodes increased, finding route to the destinations also require large and frequent exchange of routing control information among the nodes. Since, the number of update traffic increased and it is even increase more when high mobility nodes are present. High mobility nodes can impact route maintenance overhead of routing protocols, in this case may no bandwidth remain leftover for data packets transmission.

Ad hoc routing protocols can be broadly classified as being proactive (table –driven) or reactive (on-demand). Proactive protocols are directly inspired by routing protocols deployed in the Internet and consist of maintaining a routing table for sending data to any node in the network. On the other hand, reactive protocols research the vital information of a route between two nodes when a request for this route is expressed by the higher protocol layers. The protocol of this class attempt to keep the routes used and only those as up to date as possible in order to minimize the use of control messages to a minimum to save bandwidth. In brief, we can conclude that no protocol is suited for all the possible environments, while some proposals using a hybrid approach have been suggested.

Security: Wireless mobile ad hoc nature of MANET brings new security challenge to the network design. Mobile wireless networks are generally more vulnerable to information and physical security threats than fixed wired networks. Vulnerability of channel and nodes, absence of infrastructure and dynamically changing topology make ad hoc network security a difficult task [20]. Malicious and selfish nodes are fabricating attacks against physical, link, network and application layer functionality. Since ad hoc network needs mechanism such as user authenticity and key management to overcome this problem.

A basic requirement to keeping an ad hoc network operational is to enforce collaboration between nodes such as packet forwarding and routing. Each nodes assign qualifications to all the other nodes in the network, increasing the qualification when collaboration is detected and otherwise decreasing it. Those nodes that does not collaborate in this network is called misbehaving nodes, which routing forwarding misbehaviors caused by malicious or selfish nodes. A malicious node does not collaborate with other nodes in the network because it wants to intentionally damage network functioning by dropping packets. On the other hand, a selfish node does not intend to directly damage other nodes, but is unwilling to spend battery, CPU cycles, or available network bandwidth to forward packets not of direct interest to it.

Quality of Service (QoS): Providing Quality of Service is a very complex problem in Mobile ad hoc networks, which make it a challenging area for research in MANETs because the dynamic networks environment with continuous topology changes and the limited resources raise the problem of QoS support at different levels. Providing complete QoS solution for ad hoc networking environment requires interaction and collaboration between several components such as QoS routing protocol, resource reservation scheme and QoS capable medium access control (MAC) layer. QoS routing requires not only finding a route from source to a destination, but it need a route that satisfies the end to end QoS requirement, often given in term of bandwidth or delay.

Power Consumption: The most important issue in MANETs is maximizing life of battery, as it is very limited due to the devices characteristic, because some or all of nodes in ad hoc network may rely on batteries with limited capacities or other exhaustible means for their energy. In the network interface, energy efficiency can be improved by developing transmission and reception technologies on the physical layer, but especially with specific networking algorithms. Nevertheless, energy conservation is currently being addressed in every layer of the protocol stack.

In [21] the author present algorithm to prove that the node with the largest probability consumes the lowest energy. In order to achieve an optimum route connection by extending the network lifetime, the distance factor of the source, intermediate and destination nodes need to be combined with initial energy of the node when selecting a participating node in a route path.

2.3. Vehicular Ad Hoc Networks (VANETs)

Vehicular networks are receiving a lot of attention due to the wide variety of services they can provide. In VANETs, vehicles communicate with each other and possibly with a roadside infrastructure to provide a long list of application range varying from transit safety, crash avoidance to driver assistance, internet access and multimedia [17]. In this network, knowledge of the real time position of nodes is an assumption made by most protocols, algorithms and applications. Such networks comprise of sensors and On Board Units (OBU) installed in the car as well as Road Side Units (RSU). The data collected from the sensors on vehicles can be displayed to the driver, sent to the RSU or even broadcasted to other vehicles depending on its nature and importance. The RSU distributes this data along with data from road sensors, weather centers, and traffic control centers to the vehicles and also provide commercial services.

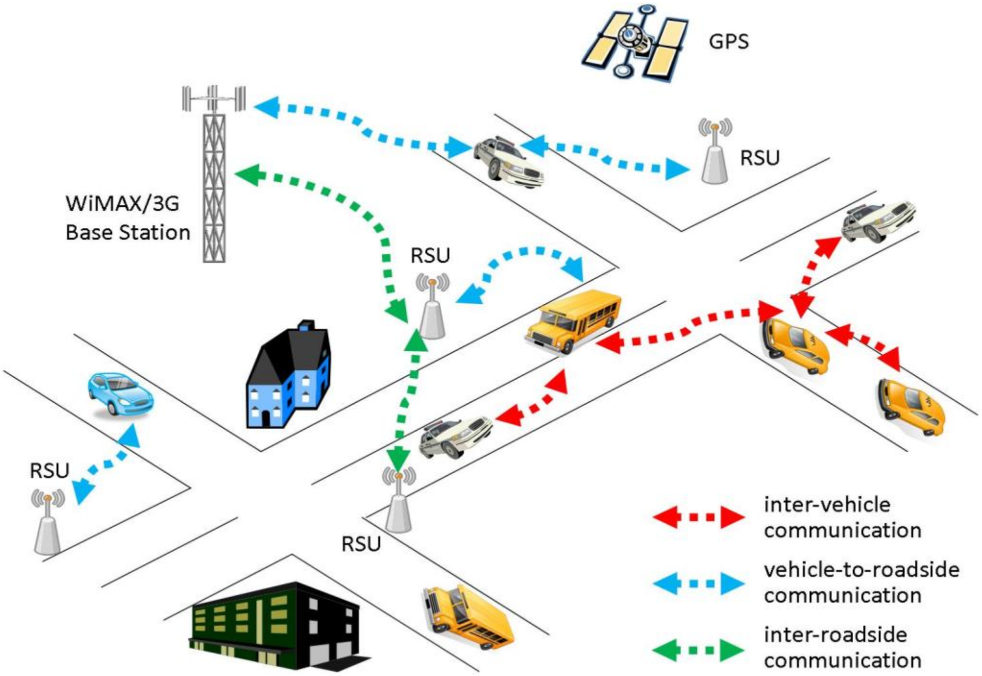


Figure 4 Wireless Vehicular Networks

VANETs are characterized by high node mobility, constrained nodes movements, obstacles heavy deployment fields and large number of nodes, which all add to the communication challenges. This network is a significant step towards intelligent transportation system (ITS). The following variety applications are some services of an ITS:

Safety: improve security in dangerous or unexpected driving situations, which a warning message will be broadcasted from a vehicle to its neighborhood notifying about some event such as car collision or road surface conditions in order to decrease traffic accidents rate and enhance traffic flow control.

Resource efficiency: referring to increase traffic fluency with data such as enhanced route guidance or parking spot locator services. Better efficiency results in less congestion and lower fuel consumption, helping to minimize environmental and economic impact.

Infotainment and Advanced Driver Assistance Services (ADAS): offering multimedia and internet connectivity facility to the passengers. Multimedia content downloads directly from vehicles or content interchange between them.

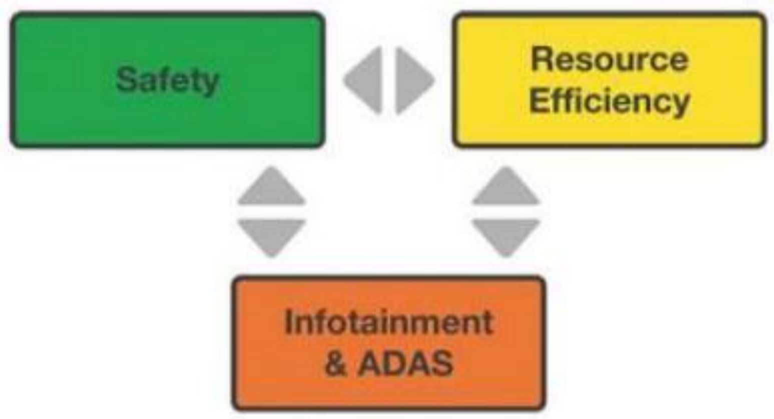


Figure 5 Application domains

The huge potential of V2V (Vehicle to Vehicle) connectivity is fundamentally due to the constant growth of automotive market and the increasing demand for the car safety. Some issues relating to architecture, routing, security, performance or QoS should be investigated. It is necessary to put special attention to ensure interoperability through the standardization of protocols and interfaces in order to allow the communication between vehicles from different manufacturers.

2.4. Routing Protocols

In this section, main routing protocols used in Ad Hoc networks and their classifications are explained. Many routing protocols with different characteristics have been designed to face different situations and scenarios over ad hoc networks. In recent years, many routing protocols for MANETs have been developed, which we focus on improving one or more points of the performance of the network. Routing protocols for Ad Hoc networks should follow next guidelines to its design:

- **Minimum signaling:** reduction in control message helps to keep batteries capacity and improve efficiency of the communications.
- **Minimum process time:** low computation power protocols are needed to decrease computational time and to increase battery life.
- **Loop free:** TTL (Time To Live) assigned to packets is low in order to avoid loops of packets through the network.
- **Inactive operation mode:** protocols must be ready for long periods of time with no activity at all from inactive nodes.

- **Distributed operation mode:** due to inherent characteristics of Ad Hoc networks.

2.4.1. Routing protocols classification

Many protocols have been proposed for MANETs. These protocols can be classified into three categories: proactive, reactive and hybrid. Proactive methods, also called table-driven methods, maintain routes to all nodes, including those nodes that do not have packets for sent. Such methods react to topology changes, even if no traffic is affected by the changes. Reactive methods, also called on-demand methods, are based on demand for data transmission. Routes between hosts are play only when they are explicitly needed to forward packets. They can significantly reduce routing overhead when traffic is lightweight and the topology changes decrease dramatically, since they do not need to update route information periodically and do not need to find and maintain routes on which there is no traffic. Hybrid methods combine proactive and reactive methods to find efficient routes, without much control overhead.

2.4.2. Proactive routing protocols

As stated earlier, proactive routing protocols maintain routes to all destinations, regardless of whether or not these routes are needed. In order to maintain correct route information, a node must periodically send control messages. Therefore, proactive routing protocols may waste bandwidth since control messages are sent out unnecessarily when there is no data traffic. The main advantage of this category of protocols is that hosts can quickly obtain route information and quickly establish a session. Several proactive routing protocols have been implemented depending on the kind of route information stored on node's tables as well as the used updating method. The most representative are DSDV (Destination-Sequenced Distance Vector) [50] and ADV (Adaptive Distance Vector) [51].

2.4.3. Reactive routing protocols

Reactive routing protocols can dramatically reduce routing overhead because they do not need to search and maintain routes on which there is no data traffic at the expense of increasing end-to-end delay. This property is very appealing in the resource-limited environment. Depending on how the routing method is implemented, reactive routing protocols can be divided in source routing protocols and hop-by-hop protocols.

- **Source routing protocols:** In source routing protocols every data packet carries the whole path information in its header. Before a source node sends data packets, it must know the total path to the destination, that is, all addresses of nodes which compose the path from source to destination. There is no need that intermediate nodes update its routing tables, since they only forward data packets according to the header information. However it entails scalability problems since as the number of hops increases, the path information every data packet must carry become major and it may waste bandwidth. Moreover, the path is established from the source node so that a bad adaptation to quickly topology changes will be performed. The most representative source routing protocol is DSR (Dynamic Source Routing) [52].

- **Hop by hop routing protocols:** Hop-by-hop routing protocols try to improve performance by keeping the routing information in each node. Every data packet does not include the whole path information any more. On the contrary they only include the address of the following node where data packet must be forwarded to get the destination as well as the destination address. Every intermediate node must look up its own routing table to forward the data packets to its destination, so that the route is calculated hop by hop. Hop-by-hop routing protocols save bandwidth and performs well in a large network since a data packet does not carry the whole path information. However, intermediate nodes must update their routing tables. The most representative hop-by-hop routing protocol is AODV (Ad hoc On-demand Distance Vector) [53].

2.4.3.1. AODV (Ad hoc On-demand Distance Vector)

AODV (Ad hoc On-demand Distance Vector) [53] is a reactive protocol, i.e. it searches and maintains routes only when they are required. The general functionality of the protocol is similar to DSR but the main difference is that the route information is stored on routing tables at each node, instead of including it on the packet header. This way, higher efficiency is achieved by reducing packet headers thus making the protocol suitable for larger networks than with DSR. This way, AODV works well in networks up to 1000 nodes). Also, the use of sequence numbers let discard obsolete routes.

Discovering routes in AODV: When a node needs to find a route towards a destination which is not in the routing tables, it sends a broadcast Route Request (RREQ) packet to all its neighbors. Nodes which receive this packet update information related to the source node and add a new route in its routing table. RREQ contains following information:

- Source node ID
- Destination node ID
- Current sequence number
- Most recent destination sequence number that source remembers.

This way, a node replies with a RREP if it is the destination node, or if it is an intermediate node with a stored route to destination with a sequence number equal or higher than the one included in the RREQ. When RREP is propagated to the origin node, intermediate nodes update its entry to that destination node in the routing table.

Route maintenance in AODV: AODV uses some mechanisms to detect if a link is broken. A first way to monitorize links status is to check if for a routing table entry, a neighbor node has sent a packet during the last active route timeout seconds. Another way is using Hello messages. Nodes can send them periodically to its neighbor nodes. If a node detects that one of its neighbors is not sending HELLO messages, the link may be broken. Finally, when no ACK packets are present, it means that the link is also broken. Once a broken link has been detected, the node sends a RERR (Route Error) to the source node of this route.

2.4.3.2. DSR (Dynamic Source Routing)

DSR (Dynamic Source Routing) [52] is a simple and efficient reactive protocol which operates entirely under demand, searching and maintaining routes only when are necessary, minimizing overhead.

This protocol is based on two main mechanisms: Route Discovery and Route Maintenance. These mechanisms let the nodes discover and maintain active the routes. One node uses the Route Discovery mechanism when it needs to discover a route to a destination. Besides, DSR uses the Route Maintenance mechanism when it needs to verify if any of the already established routes is still alive. All aspects of the protocol operate entirely on demand, allowing the routing packet overhead of DSR to be automatically scaled depending on the number of routes in use. The protocol finds out multiple routes to any destination and allows the sender to select and manage the routes. DSR protocol is designed mainly for mobile Ad Hoc networks of up to about two hundred nodes and is designed to work well even with high rates of mobility.

Route discovery in DSR: Once a node needs to send a packet to a destination, it searches in its route cache for an active route to that destination. If no route is found, a Route Discovery process starts to obtain a route. The source node sends a Route Request (RREQ) packet to all its neighboring nodes, i.e. to all the nodes under its coverage. The RREQ packet contains the identifiers of the source and destination nodes, as well as a unique ID for each RREQ. Also, the packet will append in its header all the nodes it has been routed by.

When a node receives a RREQ, it consults its cache in case there is an existing route to destination. In case of success, it answers to the petition with a Route Reply (RREP). Otherwise, it will send a new RREQ broadcast packet appending its identifier on it. If eventually the destination nodes receive the first RREQ, it must send the RREP to the origin node. If all the links are bidirectional, the process to follow is to invert the discovered route by RREQ. On the contrary, a route to the origin node has to be found in order to send the RREP packet. To avoid infinite recursivity on route discovery, RREP is included in the new RREQ that the destination node sends. It is known as Route Reply piggybacking. Once the RREP is received by the source node, it stores the obtained route in its cache. Then, the node sends data packets which include the whole route in their header. This way, each forwarding node knows where to send the packets.

Route maintenance in DSR: Each time a node sends a packet, it has the responsibility to confirm that the packet has been correctly received on the other side. This acknowledges is done at link level. A packet can be retransmitted a maximum amount of times. If after this bound the packet has not been successfully sent, the node will sent backwards a Route Error (RERR) message indicating that the current route is no longer valid. When the source node receives the RERR packet, it deletes the route from its cache and starts a new Route Discovery to discover a new route. The error message is forwarded as well as the new Route Discovery (piggybacking of the error message) to make the other nodes aware of the route breakage.

General considerations: It is not a good option to propagate RREQ packets too far because too many unnecessary RREP packets would be generated, increasing network congestion. Due to this, the protocol establishes initially a low hop number for each packet. If it is no possible to find a route, the hop number is increased until a route is found. In order to avoid collision if many nodes send RREP, a random back-off time is waited before sending a new RREP. A DSR optimization consists on letting the intermediate nodes to memorize all the possible routes. It is important to maintain the caches updated to make communications faster and collaborate replying to other node's RREQ.

DSR includes mechanisms that improve the performance of the protocol, such as packet salvaging. It consists on changing the action to do by a node that was unable to send a packet through a route. This node will try to salvage the packet retrying to send it through another route available in its route cache, instead of sending a RERR. Automatic Route Shortening (ARS) consists on cutting a route when an unnecessary intermediate node to arrive to destination is detected. In general terms, DSR is a protocol especially suitable for stable and small networks, where nodes move at slow to medium speeds, e.g. up to 20 m/s.

Flowstate Extension (FE): DSR includes this feature to be capable of sending packets without the complete route in the header, to reduce the overhead incurred in the network. It is known as "implicit source routing". Flowstate Extension is automatically initiated by the first packet which belongs to a data flow. Then, each flow is identified with a source address, destination address and a flow ID chosen by the source node. Each header of a DSR packet carries either the complete route information or the flow ID which that packet belongs to. So, intermediate nodes do not need to check the destination of each packet. Only checking the flow which a packet belongs to, it is enough to route that packet to the next hop, as the route for that flow was previously established with the first packet.

2.4.4. Hybrid routing protocol

Hybrid routing protocols combine the proactive and reactive routing approaches. They divide the network into routing zones, so that it will be used proactive routing schemes for intra-zones routing issues and reactive routing schemes for inter-zones routing issues. The most representative hybrid routing protocol is ZRP (Zone Routing Protocol) [54].

3. Video Streaming service over MANETs

A multimedia stream can be live or on demand. Live streaming refers to streaming of data from a live event, where the media data does not retrieved from stored devices, in this case streaming required for viewing live multimedia content. On the other hand, on demand streaming refers to non live streaming of media, where the media data retrieved from stored devices, hence media are transmitted to user upon the request of them.

During the last few years, as the number of multimedia devices which maintain wireless communication and the number of end user who require multimedia services increased, the demand for multimedia content have increased too. Nowadays, multimedia application and especially video streaming are some of the most demanded services. In many situations and areas, these demanding of users may spontaneously form infrastructureless ad hoc network to share their resources and content. These types of applications have QoS requirements that must be accomplished to achieve a certain level of quality at the customer side. Since, it is necessary to make a research effort to propose efficient frameworks capable of providing QoS in MANETs Environments.

3.1. QoS support for video streaming

In this chapter we overview some techniques used to assist the provision of QoS in video streaming services, such as video compression, application layer of QoS control and protocol of QoS support.

3.1.1. Video Compression

As video takes up a lot of space, must apply techniques to compresses and reduce redundancy in video data. So, video compression techniques are used to reduce the amount of data storing digital video images. Video generate large file due recorded without compression, which it is hard to manipulate and distribute. Since, apply video compression to generate smaller file can be more efficiently to distribute through network. Video compression may effect on video quality and in some cases is impossible to restore the original video. Most video compression combines spatial image compression and temporal motion compensation.

There are two type of compression for video, lossy and lossless compression, which lossy compression is the most majority of video compression and bit rate is lowered by discarding data. In other hand, the lossless compression keeping almost all the data, although the space occupied is smaller than lossy technique. Video compression techniques usually operate on square-shaped groups of neighboring pixels called marcoblocks, blocks of pixels are comparing one frame with the next frame and the video compression codec (encode-decode scheme) send only differences between these blocks [22]. In terms of technical design, the most significant enhancement in MPEG-2 related to MPEG-1. The technique we are used for video in this thesis is based on MPEG-2.

3.1.1.1. MPEG-2 format

MPEG (Moving Picture Experts Group) is a standard method for transmit digital video and audio in compressed format using less bandwidth than traditional analog method. MPEG-2 is an extension of the MPEG-1 international standard for digital compression of video and audio signals, which officially adopted by ISO (International Organization for Standardization). MPEG-2 format have fixed many problems of MPEG-1 such as resolution, scalability and handling of interlaced video. It is directed at higher data rates at broadcast formats. Also it is capable of coding standard definition television at bit rates 3-15 Mbps and high-definition television at 15-30 Mbps [23]. This format allows multiple channels to be multiplexed into a single data stream at various bit rates.

Three picture types are defined by MPEG-2 encoded video:

Intra-coded Pictures (I-Pictures): I-frames encode spatial redundancy and coded without reference to other pictures. They are the base layer and provide basic video quality. The most important video information for the decoding is carry by I-frames. They are absolutely necessary for decode the video sequence.

Predictive-coded Picture (P-Pictures): P-frames can use previous I-frames or P-frames for motion compensation and may be used as a reference for future prediction. They provide enhancement layers, so that granularity scalability can be achieved. They carry differential information from preceding or next frames.

Bidirectionally-predictive-coded Picture (B-Pictures): B-frames can use the previous and next I-frames or P-frames for motion compensation. They have same behavior like P-frames such as provide enhancement layers and carry differential information from preceding or next frames.

P-frames require less coding data, around 50% compared to I-frame size and B-frames need even less coding data than P-frames, around 75% compared to I frame size. Therefore, I-frames should have the highest priority whereas B-frames should have the lowest one.

These three types of pictures are combined to form a GoP (Group of Pictures), which each ones have 4-20 frames. I, P and B frames follow a unique frame patterns in a video, which is repeated at each GoP. The GoP can be decoded even when I frames are present. A typical GoP is formed by 15 frames and in order to form a GoP, P-frames and B-frames might follow an I frame, i.e. [IBBPBBPBBPBB]. However, other GoP structures standard can be used.

In this work, we use an MPEG-2 VBR (Variable Bit Rate) codification video flow, thus the video rate vary through the time. However MPEG-2 VBR is capable to maintain the same video quality in the coded stream. Alternatively, an MPEG-2 CBR (Constant Bit Rate) codification would maintain a constant video rate but a variable video quality.

3.1.2. Application layer QoS control

Application layer QoS control techniques are employed at the application layer to control packet loss and transmission delays due to network congestion. There are two types of application layer: Congestion Control mechanisms and Error Control mechanisms, where congestion control mechanisms classified into Rate Control methods and Rate Shaping methods and Error Control mechanisms consist of Forward Error Correction (FEC), Automatic Repeat Request (ARQ), Error Resilient Coding and Error Concealment.

Rate control can be done either by source or receiver or both of them can operate to provide rate control. Source based rate control techniques are either probe based or model based. Probe based approaches at the source are experimental in nature and rely on obtaining feedback from the receiver to adapt sending rate to the network bandwidth, whereas model based approaches are based on the throughput model of the TCP. Receiver based rate control mechanisms require source to transmit data in separate levels of different quality. If the receiver detects no congestion happened then it optionally can increase the service quality to improve the visual quality of video, whereas if congestion is detected then receiver can just perform a graceful degradation of the visual quality of the video.

Error control techniques employ FEC add redundant information to the bit stream in case of packet losses to facilitate the reconstruction of the data. Retransmission schemes (ARQ) are applicable only in scenarios where it can obtain a lost packet through retransmission without violating its presentation deadline. Error Resilient techniques employ multiple encoding description methods to compensate packet losses. Error Concealment methods use spatial and temporal interpolation to reconstruct the lost information within or between video frames.

3.1.3. Protocol with QoS support

The Quality of Services specifies the architecture in which some of services could be provided in the network. Some applications need more stringent QoS requirements than others in the network. There are two basic types of QoS model:

IntServ (Integrated Services): recourses in the network allocate according to an application QoS request and subject to the resource management policy (.e.g. bandwidth). A resource reservation in IntServ is provided per flow. A flow is defined as an individual, uni-directional, data stream between two applications (sender and receiver), it identified by set of five parameters such as: transport protocol, source address, source port number, destination address and destination number.

InteServ is implemented with four main components such as: the admission control routine, signaling protocol, classifier and the packet scheduler [24]. It is not suitable for MANETs due to the resource limitation in MANETs.

DiffServ (Differentiated Services): network traffic is classified into a few number of classes and allocated according to the resource management policy. DiffServ is designed to overcome the difficulty of implementing and deploying IntServ in the internet backbone [24]. It is provide limited number of aggregated classes to manage the traffic. An aggregate is simply constituted by set of individual flows. DiffServ is a lightweight overhead model that may be more suitable for MANETS. However, DiffServ is designed for fixed wire networks, but still there are some challenges to implement it in MANETs.

Application, network topology and policy dictate which type of QoS is most appropriate for individual flows or aggregates. There are number of QoS protocols and algorithms to accommodate the need for different type of QoS:

Resource Reservation Protocol (RSVP): it is adopted as the signaling system in the internet to enable network resource reservation. Although typically used on a per flow basis i.e. IntServ and it also used to reserve resources for aggregates i.e. DiffServ. The main motivation for RSVP is to allow efficient support for establishing multicast and unicast connections. RSVP is not suitable for MANETs due to its inherent dynamism which it produces frequent link breakages.

Multi Protocol Labeling Switching (MPLS): it introduce the connection oriented paradigm into the IP traffic flow for aggregates via network routing control according to labels in encapsulated packet header. It directs data from one network node to the next based on short path labels instead of long network addresses.

Subnet Bandwidth Management (SBM): it is a signaling protocol that enables categorization and prioritization at layer 2 (data link layer in OSI model) such as RSVP on the shared network and switched IEEE 802-style networks.

Nevertheless, these protocols can not apply directly in MANETs, though they have been used over wired networks. Also these techniques are not useful anymore, because providing QoS over MANETs generates new challenges and efforts to develop new proposal which are capable to collaborate between all the OSI layers of the network.

3.1.3.1. User Datagram Protocol (UDP)

UDP is a simple protocol that facilitates end to end delivery of a single data packet. There is no connection setup prior to the data transmission. It has no congestion control scheme to react to network congestion. UDP provides no delivery guarantees, sequence numbering or acknowledgements of received data packets [25]. The lack of transmission delays make it suitable for real-time applications such as Voice over IP (VOIP).

3.1.3.2. Real-Time Transport Protocol (RTP)

RTP is an end to end protocol that provides network transport functions to facilitate transmission of real-time data traffic over multicast or unicast network services. This is one of the most extended transport protocols which supply some QoS support. Multimedia data is encapsulated in RTP packets and sent over the network using UDP socket interface. Since, RTP satisfies the needs of multiple participants (one RTP session for every media). RTP is very flexible and it can be used over any packet based lower layer protocol, but UDP is the usual choice. It does not guarantee QoS nor data reliable delivery. It is usually used over UDP/IP.

3.1.3.3. Real Time Control Protocol (RTCP)

RTCP accompanied with RTP to provide feedback to senders and receivers for the on-going media stream. RTCP and RTP use different transport addresses. Media senders and receivers periodically send RTCP packets to the same multicast group. RTCP packets carry control information related to the streaming of media [26]. This media can be used by the senders to adjust their sending behavior to adapt to changing network conditions. RTCP control protocol provides QoS information to the participants of the RTP session and it used for the information exchange among users for:

- Data reception quality (RR, Receiver Report)
- Data delivery (SR, Sender Report)
- Session participants (SDES, Source Description)

The receiver nodes periodically send RTCP-RR packets to the sender and the feedback information is relative to each source. The RTCP-RR information is useful for adaptive applications. Overload of the network due to the high loss rate, thus the source should reduce its sending rate e.g. adaptive coding. It may produce a scalability problem since every source receives RTCP-RR packets of all the receivers, so there is a chance that packets collapse the source. There is a solution for this problem, send the RTCP packets with lower rate. Regarding to group size and available bandwidth, selection of RTCP-RR packets transmission interval is fundamental. The larger group (the lower bandwidth) should have the larger transmission interval. In this way, there is a reasonable RTCP packet proportion and their loss is avoided in case of congestion. The RTCP traffic must be lower than 5% of total session bandwidth [26].

3.2. Multipath routing techniques over Ad Hoc networks

The idea of multipath routing is not new. It always has been a favorable alternative both for circuit switched and packet switched networks, as it provides as easy mechanism to distribute traffic and balance the network load, as well as provide fault tolerance. There are several proposals for multipath routing protocols in AD Hoc Networks, such as [27, 28, 29, 30, 31, and 32]. Many proposals are modifications or extensions of AODV and DSR protocols, which they are mainly intended to discover a single route between a source and destination node [33]. Multipath routing is concerning to find multiple routes between a source and destination node. Multiple paths between source and destination are used to compensate for the dynamic and unpredictable nature of ad hoc networks.

Multipath can provides fault-Tolerance, load balancing and higher aggregate bandwidth. From fault tolerance perspective, this is important to avoid possible criteria points of failure. Therefore, in case of failures multiple paths between sender and receiver can robust the network by letting a fast path recovery. Load balancing is an important feature for multimedia applications over MANETs, which it can achieved by spreading the traffic along multiple routes. This can decrease congestion and bottlenecks and end to end delay. Multipath routing and load balancing using multiple description video streams in Ad Hoc networks make possible to achieve QoS provision and transmission security enforcement [28]. The bandwidth may be limited in a wireless network, routing along a single path may not provide enough bandwidth for a connection. Since, path diversity makes possible to manage applications and it require some minimum resources like bandwidth.

Maintenance of multiple paths between two end to end communicating hosts can be a problem in a MANET environment because they consume more network and node resources. The most of multipath routing proposal for improving the performance of the network have focus on a single QoS parameter (e.g. bandwidth or delay) but in this work, we are consider several QoS parameters, where each of them is relevant to obtained final video quality.

3.3. Network performance measurements

Network performance measurements describe the several factors which affect the overall performance of a network when the multimedia services transport over a network. Most of them are common for measuring the performance of the network. While, some of them are specific for MANETs, such as Delay, Delay jitter, packet losses, throughput, number of hops of a path and the end to end bandwidth.

3.3.1. Delay

Delay in the network specifies time duration of a packet to travel across the network from one node or endpoint to another node and endpoint. It is typically measured in multiples or fractions of seconds, while delay in the MANET is measured range from milliseconds to hundred seconds. The network delay consists of several parts:

- **Processing delay:** is the time that routers take to process the packet header.
- **Queuing delay:** it is concerning time that packet wait in the routing queues.
- **Transmission delay:** it is concerning about time that sending bits of packets into the link.
- **Propagation delay:** concern about time for a signal to propagate through the channel to reach to its destination.

In this work, measuring of the packet delay has been done by analyzing the trace file, where they are generated at each simulation.

3.3.2. Delay jitter

Delay jitter or packet delay variation (PDV) is a measure of the variability for a series of one way latency measurements. Jitter depends on the specific design and structure of the network topology, the traffic condition and devices used. Packet delay jitter may result from packets taking different paths to their destination to avoid congested areas or failed links. However, jitter is mainly caused by varying queuing delays encountered by packets at nodes [34]. Delay jitter is a parameter for measuring QoS of multimedia services. In the multimedia stream, the jitter may be stopped by dimensioning reception buffers with enough capabilities in order to reduce the possible irregular effect that may distribute the final video quality, when a required video frame is not available to be decoded and displayed.

In this work we used RTCP protocol, which includes a delay jitter computation algorithm. This is an estimation of the statistical variance of the RTP data packet interval time, which measured in timestamp units.

3.3.3. Packet losses

Packet losses can happen when one or more packets of data travelling through a network fail to reach their destination. There are many factors for loss a packet such as collision, an insufficiently strong signal, link breakage and channel congestion. Packet losses demonstrated as the percentage of packets loss divided by the total number of packets sent by the source. There is a direct relationship between packet loss and packet delivery.

In this work, we have focused on the number of received packet losses of each type of the video frame (I, P and B frames). The reason is that different priorities are given to each type of video frames regarding to their relevance in the video stream.

$$P_{loss}\% = \frac{P_{sent} - P_{received}}{P_{Sent}} \,.\, 100 \qquad (1)$$

3.3.4. Throughput

It refers to the volume successful of data that can deliver through a communication link. Normally, the throughput measured in bits per second (bps) or can be measured as data packet per second. There are some factors that must take into account when computing throughput such as, packet headers, waiting time, signaling packets, packets retransmission and collision. Throughput of the system computes as below equation, where ‘Data’ corresponds to the actual data and ‘T’ to the total time the source node has been transmitting.

$$Throughput = \frac{Data}{T}\ [bps] \qquad (2)$$

3.3.5. End to end available bandwidth

The available bandwidth is major important factor for measure the congestion control, QoS performance and streaming application on the network. It used to measure the maximum available bandwidth between two communication nodes. In this work, focus on the measuring which is the bottleneck of the link in each path to obtain the maximum available bandwidth between source and destination nodes.

$$Path_{av\ BW} = \min(av\ BW_{link})\ \forall\ link_{path} \qquad (3)$$

3.4. Video performance measurements

Measuring the quality of a transmitted video includes several steps. Especially retrieving video quality indexes usually requires doing a frame by frame comparison either in the raw format of the original video with the received video. Regarding video quality, measuring is based on subjective and objective measures. In the objective measures, the computation of color value obtained from each frame of video, but in subjective measures they are obtained from controlled experiments by using human subjects in order to investigate the perceived quality of video sequences. Relationship between subjective and objective is an interesting field of research, where many research have been provided. For instance in [35, 36] the authors made a relation between PSNR (Peak Signal to Noise Ratio) and MOS (Mean Opinion Score). The reason is, may a video with better marks on an objective metric obtain worst marks on subjective metric. Normally, both objective and subjective metrics fail to differentiate between different scenarios when transmission conditions become very poor, they experiencing a saturation effect at the lower edge of the metrics range.

The author in [37] relied on different metrics (PSNR, packet loss ratio and frame losses) in order to determine the impact of different transmission impairments on the quality of streamed video sequences as experienced by the receiver. This set of metrics are quite adequate in the context of video transmission over lossy IP networks, which they assess video quality from different perspectives.

The video performance metrics for image of MxN pixels are:

- **MSE (Mean Square Error):** it used to measure the average of squares of errors and compare image comparison quality. It is represents the cumulative squared error between the compressed and original image. The error is the amount by which the value implied by the estimator differs from the quantity to be estimated. The lower value of MSE implied to the lower error.

$$MSE = \frac{1}{M.N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}[I_{org}(i,j) - I_{dec}(i,j)]^2 \qquad (4)$$

  In the MSE equation, I_{Org} stand for original Image and I_{dec} for decoded image of MxN pixels.

- **PSNR (Peak Signal to Noise Ratio):** it used to computes the quality comparison between two pictures (compressed and original picture) in term of dB (decibel). PSNR is an objective measure of the video performance while the subjective video quality notices by users. The higher PSNR implied to higher quality of image compression process. This metric have been used in our performance evaluation.

$$PSNR = 10\,.\log\frac{MAX^2}{MSE} \qquad (5)$$

In PSNR equation, MAX is the maximum fluctuation in the input image data type. In case of 8 bit image, MAX = 255.

- **RMSE (Root Mean Square Error):** it used to measure the differences between values predicted by a model or an estimator and the values actually observed from the environment that is being modeled. RMSE is part of the PSNR, since it used to assess how well a method to reconstruct an image performs relative to the original image.

$$RSME = \sqrt{MSE} \qquad (6)$$

These metrics provided to test video comparison codec in case of degradation of compressed data and no frame losses. In our work, frame losses are present due to congestion in the network, where every lost frame identifies. Therefore, the objective measure of the video performance is to compares the arrived frames at destination with the original frames that were sent (from the source).

4. MMDSR: Multipath Multimedia Dynamic Source Routing Protocol

This chapter gives an overview about MMDSR technique to support multiple video sources and find a best path among the available paths for sending a multimedia content from a single source node to single destination node by using DSR routing protocol. It is able to improve the performance of video streaming services by applying cross layer algorithms and multipath routing techniques. All layers of protocol collaborate to each other to achieve the goal of QoS provision. MMDSR deals to the selection of path, operation, control packet and classification of path in the network [38].

4.1. Multipath routing scheme

Regarding to the proposed research in [38], MMDSR uses extension of DSR as a routing protocol to find available path in the network. In this scenario the number of path should not exceed more than three paths at a same time, due to excessive overhead increase and small improvement. According to our framework, there are three paths and three type of frame (I, P and B) which a priority defined for each frame. The most important video coded frame (I-frame) send through the best path, while the second important frame (P-frame) send through second best path and then the last frame which is B-frame send through the last path. In case of two paths, I frames would send through the best path and then P and B frame send through the second available path. And if there is only one path available, all the frames should be sending together through the same available path.

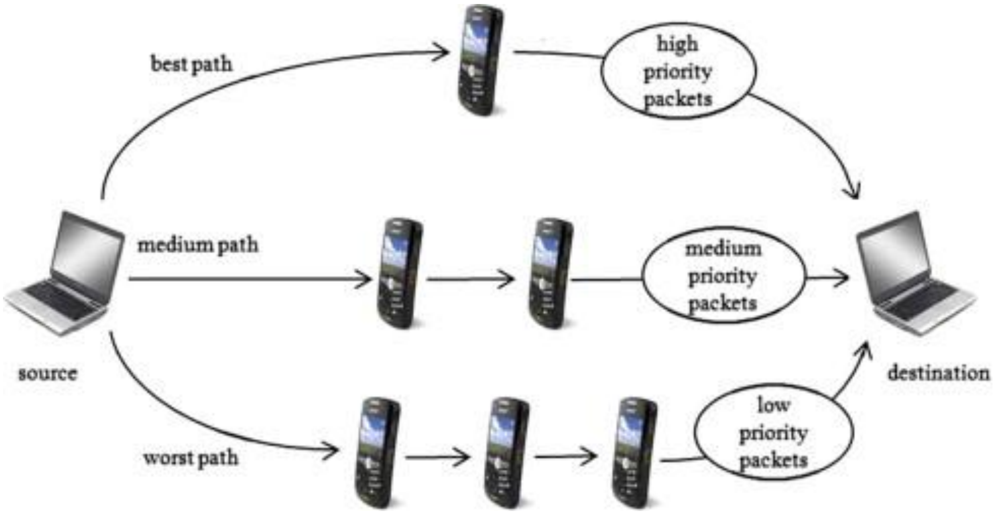


Figure 6 Multipath routing scheme (using three paths)

In this case, we use minimum bandwidth (BW_{min}), maximum fraction of packet losses (FPL_{max}), maximum delay (D_{max}) and maximum delay jitter (J_{max}), In order to meet the customer requirements and medium QoS parameter and achieving good video quality.

$$Customer_{req} = \{BW_{min}, FPL_{max}, D_{max}, J_{max}\} \tag{7}$$

In the next chapter (chapter 5) we will discuss about the game theory technique which it work with multipath routing scheme to arrange video frames in different manner to obtaining better outcome according to the routing game.

4.2. MMDSR operation and control packets

According to the structure of MMDSR, all the decisions and operations are taken from sender node and they depend to the state of the network. In case of communication between two nodes for video streaming, MMDSR using DSR routing engine to discover the available path between source and destination nodes. Prior to the start of a video transmission between these two nodes, the source node sends a Probe Message (PM) to the destination through the D paths, which already discovered by DSR routing engine. Then destination generate Probe Message Reply (PMR) packet that contain set of information regarding to QoS parameters collected from the PM packet that arrived to the destination. The destination send PMR message to the source node through the paths that PM arrived. The information of PMR will analyzed at the source in order to assign a score to each paths and classify them. Finally, source selects the number of paths that needed by the multipath scheme.

This process is repeated over time with a certain period in order to refresh paths, as the nature of MANETs which is dynamic it may produce link breakages and thus the topology can vary during the time. The Qos parameters computed for each available path is collected in a vector, called path-state.

$$path - state_k^i \equiv \{BW, FPL, D, J, H, RM, MM\}_k^i \tag{8}$$

In the path-state, 'i' stand for number of iteration of algorithm and 'k' refer to each one of the 'K' selected paths ($K \leq D$) to compose the multipath scheme. (BW) is available bandwidth, (FPL) is fraction packet loss, (D) is delay, (J) is delay jitter, (H) is hope distance and two new Qos parameters that have designed in [39] for MANETs are: (RM) Reliability Metric and (MM) Mobility Metric.

- **RM (Reliability Metric):** it is computed from the SNR (Signal to Noise Ratio) of the links and applied to each path.
- **MM (Mobility Metric):** it is computed from relative mobility of the neighboring nodes within each path.

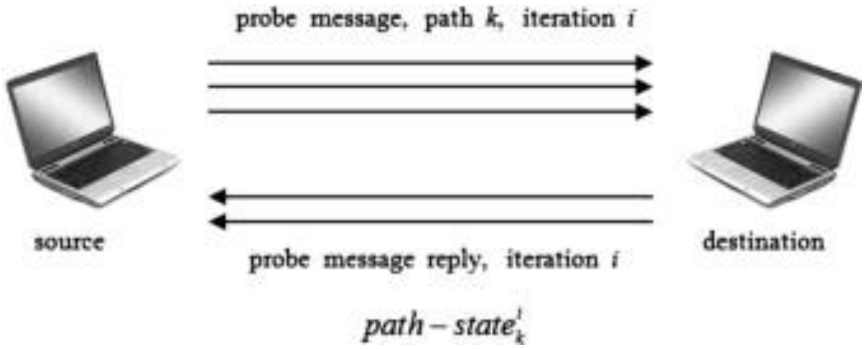


Figure 7 PM and PMR packets

4.2.1. Hello Messages

In order to compute the two QoS parameters of MANETs such as Reliability Metric (RM) and Mobility Metric (MM), we used Hello Messages (HM) periodically as assistance to monitor the perceived signal strength of the neighboring nodes. Nodes send HM once a second through those paths that are involved in a video transmission. Once a HM is received, the reception node computes the SINR (Signal to Interference plus Noise Ratio) regarding the received packet and then attaches this value to a Hello Message Reply (HMR) which is sent back to the source of that HM packet [39].

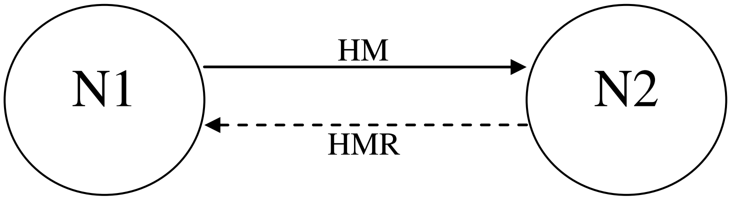


Figure 8 HM-HMR packets interchange between node N1 and neighbor

4.3. QoS parameters

In this section we describe about QoS parameters for choosing available paths from source to destination for sending video frame. Therefore, source uses feedback information to sort the paths regarding their quality and then choose the best paths to organize the multipath routing scheme.

4.3.1. Reliability Metric (RM_k^i)

The Reliability Metric (RM) computed by authors of [39] as a performance measure of the whole signal quality of a path ‘k’ for each iteration ‘i’ of the algorithm. In this way, an average qualification assigned to each path ‘k’ computed from the individual SINR values of the links that compose that path. Actually, the higher SINR in the link implies the higher RM qualification of the path. In addition, RM qualifications depend on *NState* variable that changes during time and tracks the state of the network when the algorithm is in the previous state. Since RM_k^i depends on $NState^{i-1}$. As mentions in equation (4.1) $NState$ (Network State) computed when source received the feedback information that carried in the current PMR packets, which contain the average qualifications from all the paths in multipath scheme for the metric.

$$NState^i = w_{RM}.\overline{RM^i} + w_{MM}.\overline{MM^i} + w_{BW}.\overline{BW^i} + w_P.\overline{FPL^i} + w_d.\overline{D^i} + w_j.\overline{J^i} + w_h.\overline{H^i} \tag{9}$$

In this equation upper bars denote averages and the 'w' are appropriate weights. The weighting values for each parameter, which have one, will have a higher or lower value depending on the relevance we want to give to each parameter.

$$w_{RM} + w_{MM} + w_{BW} + w_P + w_d + w_j + w_h = 1 \tag{10}$$

The proper routing period ($T_{routing}$) to be used by adaptive-MMDSR is varies dynamically and it is depending on $NState$. It computed according this function:

$$T_{routing}^{i+1} = a * NState^i + b \tag{11}$$

4.3.2. Mobility Metric (MM_k^i)

In the Mobility Metric, the higher the relative mobility of a node with respect to its neighbors implies to the lower assigned mobility metric MM_k^i of path 'k' during iteration 'i'. Similarly to Reliability Metric, Mobility Metric depends on the state of the network during the previous iteration ($NState^{i-1}$), in order to track the dynamism of the network.

More detail for computation of Mobility Metric have described in [39].

4.3.3. Hop Metric (HM_k^i)

In the current algorithms iteration 'i', Hop Metric computed by the number of hops of the longest available path and the shortest available path. Qualifications are assigned to the each path regarding the lengths of the paths, so the shortest paths get higher scores. Therefore, shorter paths are preferred because fewer losses will take place in the shorter paths due to the contention for the medium produced in every hop.

4.3.4. End to end Bandwidth Metric (BW_k^i)

The end to end available bandwidth (BW_k^i) of each 'k' paths are collected by PM packet as well. According to that, destination computesBW_k^i, which corresponds to the bandwidth of the bottleneck link (the link that has lower bandwidth) in the path. Afterward, destination sends back BW_k^i to the source in the PMR packet. Finally source computes BW_k^i Metric qualifications that assigned to each path. Since, paths with higher available bandwidth obtain higher scores.

4.3.5. Fraction of packet losses (FRL_k^i), delay (D_k^i) and delay jitter Metrics (J_k^i)

Basically PMR packet send by destination node contains the sampled of each path. Therefore, when the source node received the PMR packet can compute the metric of losses, delay and delay jitter for each *'k'* path in the current iteration *'i'*. Then those paths that have lower losses (FPL_k^i), delay (D_k^i) and delay jitter (J_k^i) get higher marks for the respective metric.

4.4. Path classification

In this section we classify available paths according to the customer requirement set in equation (4.1). In this way, the algorithm arranges those paths by checking consecutively the qualifications of the parameters as follows in the next list. Then according to the qualifications parameters source selects the number of paths required by multipath routing scheme.

(a) $RM_k^i + MM_k^i$

(b) H_k^i

(c) BW_k^i

(d) $FPL_k^i + J_k^i$

(e) D_k^i

Among several possibility, RM and MM chosen as the most important parameters to classify path, because most reliable and stable paths are preferred to distribute video streaming services over MANETs, which are inherently dynamic. The hop-count is the next metric to classify paths in drawing, since each additional hop in the path may increment the chance of collision, so the shortest paths are preferred. Bandwidth, losses delay jitter and delay are less deterministic metrics in this network, although they are taken into account as well.

4.5. Static Multipath Multimedia Dynamic Source Routing protocol (s-MMDSR)

Static-MMDSR is a multipath routing protocol based on DSR Protocol which works simultaneously with cross layer algorithm. Regarding to [40], s-MMDSR protocol operates at a fixed routing period of 10 seconds. Since, a new iteration of the algorithm start for every 10 seconds in order to refresh, manage and qualify the paths, independently of the fact of being still useful or not. According to QoS parameters the thresholds to classify paths in s-MMDSR are fixed.

The reason of using s-MMDSR is losses decreased compare to the DSR. This decrease is due to the load balancing done at the intermediate network interfaces of each one of the paths and to the use of multipath techniques which transmitting the most relevant packets through the best available paths. Since, we are able to distinguish the good paths from the bad paths to obtain better performance. In this case, I frame does not have too much losses when using static-MMDSR, as they have higher priority than P and B frames. Also they are transmitted through the best available path found by the multipath routing algorithms which should be the most reliable and stable with higher bandwidth and lower losses and delay. In addition, static-MMDSR uses the available resources more efficiently and decreasing the end to end delays. Since, we do not saturate the best path with low priority packets (P and B frames) in order to other video streaming transmissions could use the better paths to send their high priority packets (I-Frames).

The drawback of Static-MMDSR is when we applying the classification algorithm in static and low-mobility scenarios it is usual to find some paths with the same marks between source and destination nodes. And in high traffic situations all the path would obtain bad value in their qualification. The reason is the lack of enough resolution that made the system unable to distinguish paths. Also with the fixed period of the algorithm the amount of traffic overhead generated will be the same either under low traffic and low mobility situations than saturated conditions.

4.6. Adaptive Multipath Multimedia Dynamic Source Routing protocol (a-MMDSR)

Adaptive-MMDSR is a multipath routing protocol that able to self configure dynamically depending on the state of the network. Adaptive-MMDSR includes cross layer techniques which improve the end to end performance of video streaming service over IEEE 802.11e ad hoc networks. This is an improvement framework of static-MMDSR protocol.

Regarding to [39], the main improvement of this protocol is to transform the fixed network parameters of s-MMDSR to the dynamic parameters. Therefore, a-MMDSR has ability to adapt itself according network dynamism. The adaptation is fulfilled applying a correction factor to adjust dynamically the thresholds of the algorithm to assign qualification. This correction factor varies as a function of the collected values of the quality parameters of the paths. Because of this dynamic adjustment of thresholds the resolution to classify paths increased. Hence, the system is able to classify paths better. Afterward, the amount of management overhead reduced and it leading to a better use of resource, which are so scarce in this environments.

Depending to the error probabilities of the path, the iteration period of the algorithm will be changed. The lower error probability of the path implies to the higher iteration period. Since, lower overhead produced good and stable situations. In other word, the higher error probability of the path implies to lower iteration period, so in case of high mobility new paths are searched sooner since the topology varies frequently.

Adaptive-MMDSR has two new parameters than static-MMDSR such as Network State ($NState$) and Hop Metric which they have been introduced in previous sections (4.3.1 and 4.3.3). As mentioned already, the $NState$ used to tracks information about the global network state and it updated by algorithm iteration by iteration. And Hop Metric used to scoring the paths in the path classification algorithm, in order to find the shorter paths.

5. Game Theory for sharing resource on MANETs

The objective of game theoretic proposal is improving the performance of the service in order to decrease packet losses. Since, in the game theory each source nodes has several path to transport the set of frames of a video flow, which these frames can split through these paths. Nodes play routing game to distribute these video frames in order to reach to the best performance. They must select proper route to transfer the video frames because the nodes in this scenario are MANET nodes.

5.1. Introduction

Game Theory is a part of applied mathematics that describes and analyzes interactive decision situations. Game theory used to predict the outcome of complex interaction among rational entities by providing analytical tool. It attempts to mathematically capture behavior in strategic situations, where success of an individual decision maker (i.e. player) depends on the choices of the others. Generally, games may be categorized as non-cooperative and cooperative games. Non-cooperative games theory is concerned about how rational decision maker interact with each others to achieve their own goals. This model is called games and the rational decision makers are players. But unlike non-cooperative game, in cooperative games, the players can make binding commitments.

According to whether moving of players are simultaneously or not, non-cooperative games can be divided into static and dynamic games. In the static game, players make their choices of strategies simultaneously without knowledge of what the other players are choosing. In the dynamic game, there is a strict order of play. Players know to move because they know when their turns are and they know what the other player have done before them [41]. Game theory provides mathematical tools and mechanisms to model the interaction among players in order to assist in the design of services in different environments (wired and wireless communication networks) to reach to the best network performance [42].

Authors in [43, 44] have been focused on game theory approach to model the multi user interaction in communication networks and determine their strategies behavior in order to solve resource allocation between competing users when sharing a constrained channel in MANETs and other wireless networks. In this work we focus on a game theoretic approach, which using multipath routing scheme to allow to the competing nodes to share the common resources in a more satisfactory way in the mobile ad hoc networks.

5.2. Basis of game theory

A game described by the number of the players participating in the game, a set of available players' strategies and a specification of payoffs for each combination of strategies. Formally, a normal (Strategic) form of a game G is given by $G = \langle N, A, \{u_i\} \rangle$ where $N = \{1,2,3, \dots, n\}$ is the set of players and the A_i is the set of action space of player i. For every player i, $\{a_i \in A_i\}$ is a particular action chosen by i so an n-tuple action, 'a' is a point in the action space. An action tuple is a unique choice of action by each player.

And $A = A_1 \times A_2 \times A_3 \times \dots \times A_n$ is the Cartesian product of the sets of available actions for each player and $\{u_i\} = \{u_1, \dots, u_n\}$ is the set of utility functions that each player i wishes to maximize where

$$u_i : A \rightarrow R$$

The utility function is a mathematical description of preferences that maps action space to set of real numbers. A utility function for a given player assigns a number for every possible outcome of the game, so that a higher number implies that the outcome is more preferred.

A pure strategy provides a complete definition of how a player will play a game. In particular, it determines the move a player will make for any situation they could face. And a mixed strategy of player i, 'α_i' is an assignment of a probability to each pure strategy.

$$p_i \in P = [0,1]$$

This allows a player to select one among set of pure strategy. Let $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_n)$ be the mixed strategy profile, then the probability of a particular n-tuple action of $a = (a_1, a_2, \dots, a_n)$ will occur, $p\,(a)$ is formed from the product of the probabilities assigned to a by α. $U_i(\alpha)$ is the expected utility to i for mixed strategy profile α, and has the following expression:

$$U_i(\alpha) \equiv \sum_{a \in A} p\,(a).\, u_i\,(a) \tag{12}$$

A mixed strategies extension to G is $G' = \langle N, \{\Delta\,(A_i)\}, \{U_i\} \rangle$, where $\{\Delta\,(A_i)\}$ is the set of all probability distributions over A_i and $\{U_i\}$ is the set of expected utilities to i. A *best response* is a strategy which produces the most favorable outcome for a player, taking other players' strategies as given. A Nash Equilibrium (NE) also called strategic equilibrium, named after John

Forbes Nash [45] who first proposed it. Nash equilibrium claim the principle of stability, means that the no elements of the system wants to change anything, so all the components are stable and want to stay forever, thus formally it means that no players has an incentive to unliterary change its strategy given that all the others are stock to the strategies. It is a mathematical fact that every mixed extension of a strategic game has at least one mixed strategy Nash equilibrium [45].

5.3. Game theoretic routing protocol

The architecture of multipath routing protocol is shown in Figure 9, so regarding to this figure, there are two connections (S_1 to D_1 and S_2 to D_2) with sharing three available paths (best, medium and worst path). In this way users always send the most important video frames which is the I-frames through the best available path founded by MMDSR in the current iteration of the network and they sends the least important video frames which is B-frames through the worst path. According to this scheme that users always want to send the I-frames through the best paths, might have congestion and higher losses so the best paths downgraded to the worse paths, and it effect to the video quality experienced by the users.

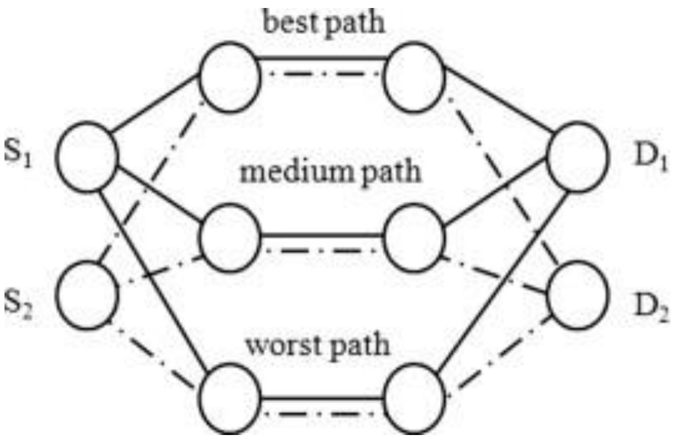


Figure 9 Fixed strategy to allocate resources

Here we give an example for understanding mechanism of the work, when streaming a video between two connections. Therefore, for simplicity of the users, worst path, which is the third path allocated for the B-frames, in order to send all the B-frames through the third path. Afterwards, the two best paths are selected by each user to send the most important video frames (I and P). Users prefer to play the game because the second best path may sometimes provide a better performance than the best path due to lower congestion. To make obvious the inconvenience of sharing the same path, I and P frames are send through the same path so there are more P frames than I frames pre flow.

As shown in Figure 10, there are four possible situations for users due applying mixed strategy. Each user chooses the best path for transmit I and P frames with certain probability. Before applying game theory, both users always select the best path for sending I and P frames, Figure 10.a. But after applying game theory three more situations arise, which under situation ‘b’ and ‘c’ of Figure 10 the user who send I and P frames through the best path have a remarkable improvement in video performance, whereas the other user have slight improvement. Hence, situation ‘b’ and ‘c’ are outperform of situation ‘a’. And the last situation,’d’, is worse than the situation ‘a’ because both users send their frames from the medium path which is the worse path among the best and medium one.

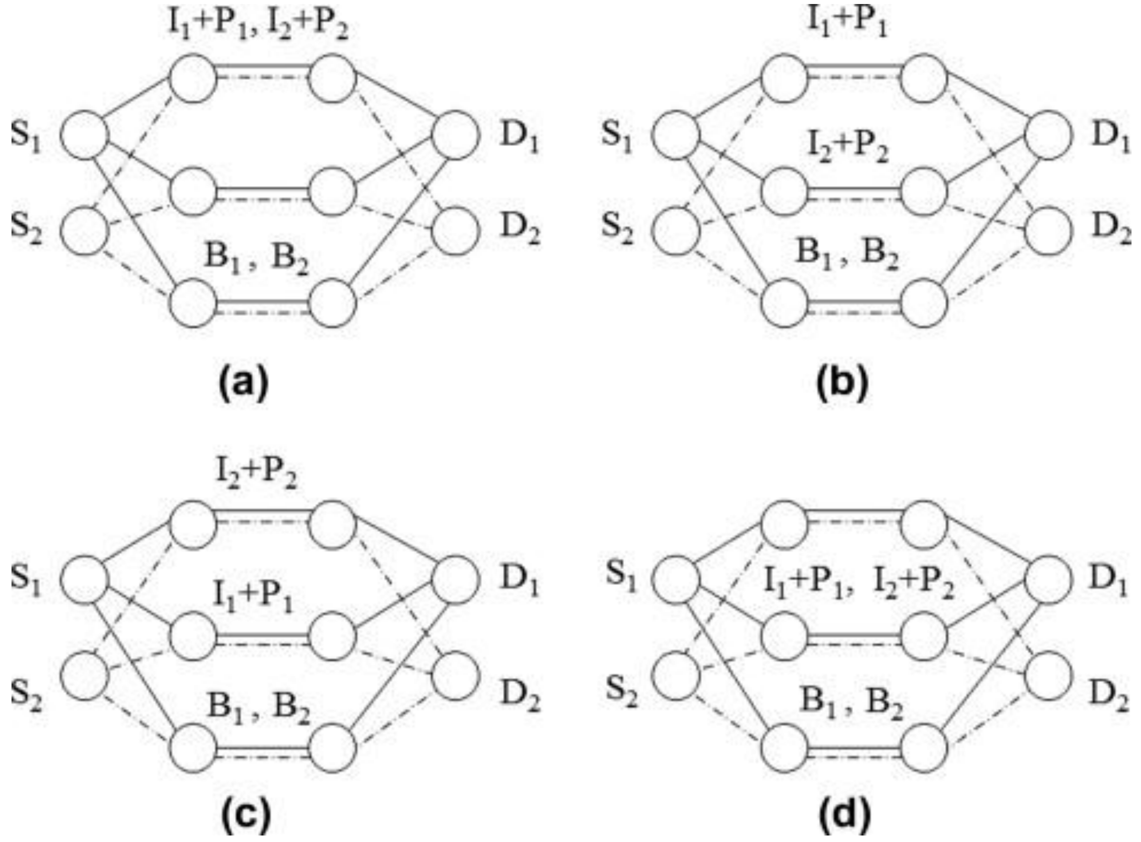
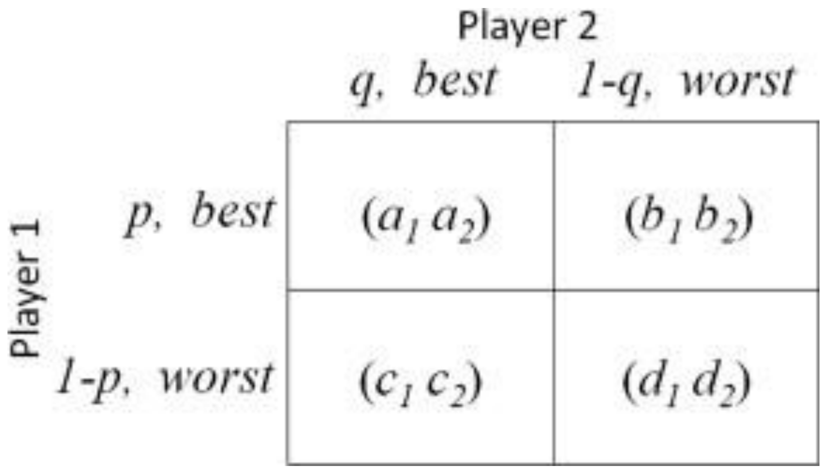


Figure 10 Four possible allocation situation after applying mixed strategy

The associated matrix of utilities or payoff is shown in Figure 11. It represents a mixed strategy that applied to the game to choose a path through which I and P frames are sent. Actions of player 1 are indexed by rows and actions of player 2 are indexed by columns. The players prefer to choice separately rather than together regarding to the preference illustrated in figure 11. The mixed strategy represents what payoff receives by each player and the probabilities to choose each pure strategy (p for player 1 and q for player 2). Each entry is the payoff vector corresponding to both simultaneous actions. $A_1 = A_2 = \{best, worst\}$ is the set of available actions for each player, where 'best' means the player selects the best path for sending I and P frames, while 'worst' means the player selects the second best available path which is the worst one among the two paths, for sending I and P frames. In the next two sections we represent how to relate the utilities with the subjective video quality in order to players decide their actions to maximize their satisfaction.



		Player 2	
		q, best	$1-q$, worst
Player 1	p, best	$(a_1 a_2)$	$(b_1 b_2)$
	$1-p$, worst	$(c_1 c_2)$	$(d_1 d_2)$

Figure 11 Matrix of utilities for routing game

5.4. End to end regulation of the user perception

As it was described in chapter 3, RTCP packets accompanied with RTP to provide feedback information to sender and receiver, because it contains information about packet losses, latency and jitter. Since, Fraction of Packet Losses (FPL) employed in the header of the RTCP packet to monitor QoS parameters of the forwarding path. According to the next equation (13), an Exponentially Weighted Moving Average (EWMA) filter used to consider the accumulated historical fraction of packet losses and the current sample using an aging factor α. This aging factor α of EWMA filter used to continuously update the FPL.

$$FPL_{historical} = (1 - \alpha) \,.\, FPL_{historical} + \alpha \,.\, FPL_{sample} \qquad (13)$$

In MANET, the best value for α is 0.25, which makes the system to detect quality changes in the paths on time without the interference of unnecessarily switching forwarding path. The reason of assigned this value for α related to the quality of the paths, because if we assigned higher value α then system become very sensitive to isolated losses, so routing scheme change forwarding paths too fast. And in case of low value for α (i.e. $\alpha < 0.25$) take much time to detect a change in the quality of the paths, which it affects to the video quality.

Regarding to packets losses we are consider two parameters for measure the quality, the first one is Peak Signal to Noise Ratio (PSNR), which is an objective measure of the degree of the difference between the original video stream and the received stream. And the second one is Mean Opinion Score (MOS), which is providing subjective evaluation of the video quality experienced by generic user. MOS uses a 5 point subjective scale, Excellent (5), Good (4), Fair (3), Poor (2) or Bad (1) [46]. Generally, a lower FPL implies to a better MOS and a better PSNR. And in other point of view, the higher FPL implies to a lower PSNR and lower MOS as well. Hence, can represent that utility function related to a user can be expressed as a function FPL experienced in the video flow of that user. In this manner, utility function can relate to the MOS and so to FPL. The relationship between this parameter (MOS, PSNR and FPL) shown in the table 1.

MOS	PSNR	FPL
5-Excellent	PSNR ≥ 30 dB	FPL < 2%
4-Good	29 dB ≤ PSNR < 30 dB	2% ≤ FPL < 4%
3-Fair	27 dB ≤ PSNR < 29 dB	4% ≤ FPL < 6%
2-Poor	25 dB ≤ PSNR < 27 dB	6% ≤ FPL < 10%
1-Bad	PSNR < 25 dB	FPL ≥ 10%

Table 1 Mapping of subjective (MOS) and objective (PSNR) video qualities and packet losses (FPL)

The video quality (MOS) and losses (FPL) are approximately related by an exponential function, so we can apply a simple exponential regression in order to obtain next expression (14), which is graphically represented in Figure 12.

$$MOS \simeq \lfloor 5 \, . \, e^{-12.FPL} \rfloor \tag{14}$$

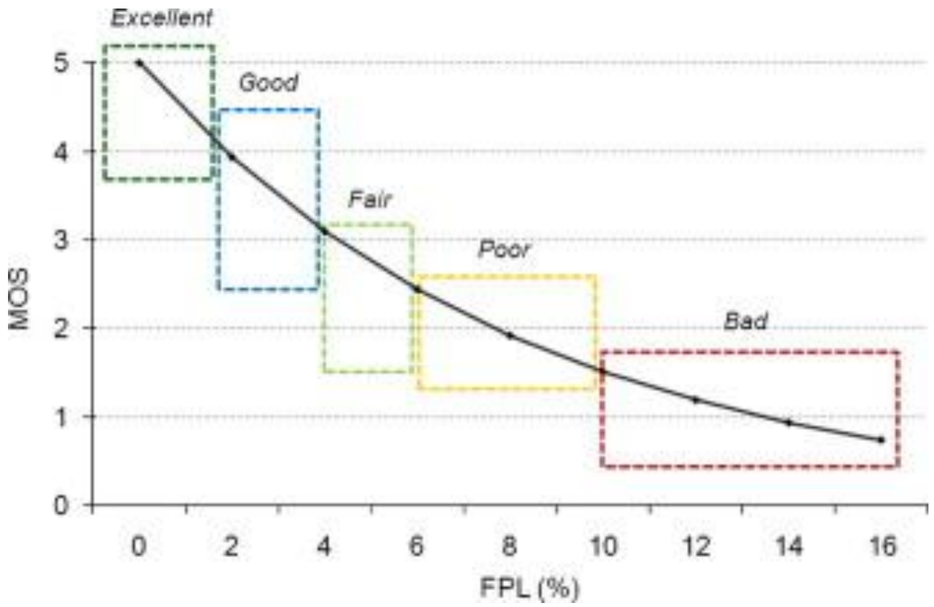


Figure 12 Subjective video quallity as a function of the packet losses

5.5. Analytical computation of users' utilities

In this section we analytically obtain through value of payoff matrix of Figure 11. In this game a best response is a strategy that a player obtain best outcome by knowing the other players' strategies. The mixed strategy (p^*, q^*) can be Nash equilibrium when the utility U_1 of player1 and U_2 of player2 respectively has next equality.

$$U_1(p^*, q^*) \ \geq \ U_1(p\,, q^*), \ \forall p \neq p^* \tag{15}$$

$$U_2(p^*, q^*) \ \geq \ U_2(p^*, q), \ \forall q \neq q^* \tag{16}$$

The utilities for the players are expressed as following equation, where $U_i(i = 1,2)$:

$$U_i(p,q) = p.q.a_i + p(1-q).b_i + (1-p).q.c_i + (1-p)\,.(1-q).d_i, \ i = 1,2. \tag{17}$$

And in case of mixed Nash equilibrium the best responses p^* for player 1 and q^* for player 2 are:

$$p^* = \frac{d_2 - c_2}{d_2 - c_2 + a_2 - b_2} \tag{18}$$

$$q^* = \frac{b_1 - d_1}{b_1 - d_1 + c_1 - a_1} \tag{19}$$

The objectives of these players are anti-coordination and best path preference which, in the anti-coordination each player would like to choose and keep their own path without interference of other player, same as situation ‘b’ and ‘c’ in figure 10. Anti-coordination utilities are expressed by next matrix.

$$M_{ant} = \begin{pmatrix} (0,0) & (a,a) \\ (a,a) & (0,0) \end{pmatrix}, \ a > 0 \tag{20}$$

But in the best path preference player always like to choose the best path for sending the I and P frames, same as situation ‘a’ and ‘b’ for player 1 and situation ‘a’ and ‘c’ for players 2 in figure 10. The best path preference utilities are expressed by next matrix.

$$M_{bpf} = \begin{pmatrix} (b,b) & (b,c) \\ (c,b) & (c,c) \end{pmatrix}, \ b \geq c \tag{21}$$

Both objectives of anti-coordination and best path preference are represented by weighted sum of both utilities matrices.

$$W_1.M_{ant} + W_2.M_{bpf} \qquad where \ \ w_1, w_2 \in \{0,1\} \ and \ w_1 + w_2 = 1 \tag{22}$$

The sum of both matrices is:

$$\begin{pmatrix} (b,b) & (a+b,a+c) \\ (a+c,a+b) & (c,c) \end{pmatrix}, \ a > 0, \ b \geq c. \tag{23}$$

If we apply these two affine transformation ($\alpha_i = 1, \ \beta_i = -c$ and $\alpha_i = \frac{1}{(b-c)}$, $\beta_i = 0$) to the following matrix:

$$\begin{pmatrix} a_i' & b_i' \\ c_i' & d_i' \end{pmatrix} = \alpha_i \, . \begin{pmatrix} a_i & b_i \\ c_i & d_i \end{pmatrix} + \begin{pmatrix} \beta_i & \beta_i \\ \beta_i & \beta_i \end{pmatrix} \; , \; \alpha_i > \quad 0, \; i = 1{,}2. \tag{24}$$

Then we get following utility matrix, which it has same Nash equilibrium than matrix (23).

$$\begin{pmatrix} (1{,}1) & \left(\frac{a}{b-c}+1, \frac{a}{b-c}\right) \\ \left(\frac{a}{b-c}, \frac{a}{b-c}+1\right) & (0{,}0) \end{pmatrix} \tag{25}$$

We assign $\frac{a}{b-c}$ to 'A' to simplify the utility matrix (25), so we have the following utility matrix:

$$M_{utilities} = \begin{pmatrix} (1{,}1) & (A+1, A) \\ (A, A+1) & (0{,}0) \end{pmatrix} \tag{26}$$

After applying equation (17) to the matrix (26), then utilities U_1 and U_2 for both players are as follow:

$$U_1 = \; U_2 = (2A + 1) \, . \; p - 2 \, . \; A \, . \; p^2 \tag{27}$$

There are three different cases, where $A < 1$, $A = 1$ and $A > 1$. And depending on the value of 'A' our routing game would have Nash equilibrium points in pure or mixed strategies.

- In case of **A<1,** the only Nash equilibrium is pure strategy (best, best) and there is no mixed strategy equilibrium. So according to equation (18) we obtain $p^* > 1$. This case is not useful in MANETs, so only equilibrium are corresponds to both users that always sharing the same path without alternative path.
- In case of **A=1,** we have three pure strategies, such as (best, best), (best, worst) and (worst, best), which the (best, best) strategy is not optimal in Pareto sense, since one of the players can obtain more benefit if both agreed on any of the other two equilibria points [47]. Since the two other pure strategies (best, worst) and (worst, best) are not acceptable by both players because they cannot use the best path equally. They can only use best path equally when using mixed strategy.

- In case of **A>1,** we have pure Nash equilibrium of (best, worst) and (worst, best) as previous case and also we have mixed Nash equilibrium which the best respond are represented as following equation:

$$p^* = q^* = \frac{1}{2}\left(1 + \frac{1}{A}\right),\ 0.5 \leq \{p^*, q^*\} < 1 \tag{28}$$

Since the only case of interest is when A>1, because only in mixed strategies players are able to change paths from one to other with certain probability.

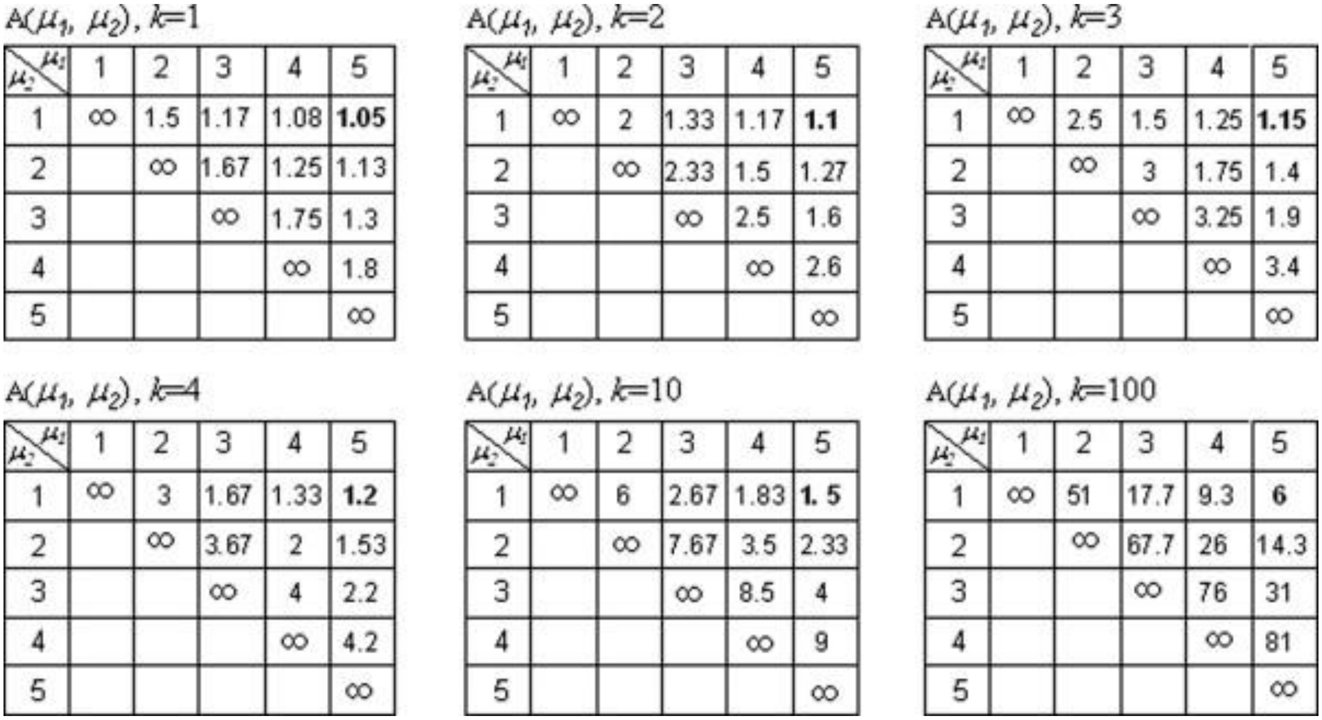
Here, we relate the utilities in matrix (26) with the video performance experienced by the users in terms of the MOS, where it has integer number from 1 to 5. Since we obtain a formula (29) for evaluating 'A' as a function of $\mu_1$and μ_2, where $\mu_1 \geq \mu_2$. In this case μ_1 and μ_2 are called as MOS and correspond to the two paths in the routing game. The MOS values $\mu_1$and μ_2 can be estimated from the packet losses that captured from each path. The next four conditions must take into account in order to have best outcome:

- $A\ (\mu_1, \mu_2) > 1$, So in this case the routing game has a mixed Nash equilibrium that the best response is equation (28). It has result in $0.5 \leq \{p^*, q^*\} < 1$.
- $A\ (\mu_1, \mu_2) = \infty$ if $\mu_1 = \mu_2$. In this case if both paths performed same then players should select paths randomly. It means that $p^* = q^* = 0.5$ so according to equation (28) A is ∞.
- $A\ (5{,}1) \approx 1$ so in this case $p^* = q^* \approx 1$. Since both players tend to choose the best path because, the best path have maximum possible of MOS ($\mu_1 = 5$) and the worst path have minimum possible MOS ($\mu_2 = 1$).
- A decreases when μ_1 increases or μ_2 decreases, so p^* and q^* are increase according to equation (28). In this case the difference in the quality between both paths increase. Since anti-coordination gets less important and players would not care too much about it when they sharing the best path.

We have following formula according to the above conditions:

$$A\ (\mu_1, \mu_2) = 1 + k \cdot \frac{\mu_2}{(\mu_1 - \mu_2) \cdot \mu_1},\ k > 0 \tag{29}$$

As shown in the next figure.13, the value of 'k' is chosen as constant (K = 1, 2, 3, 4, 10 and 100). Since the high value of 'k' (k = 100) give us $p^* = q^* \approx 0.5$, in this case μ_1 and μ_2 dose not have effect for choosing the best path. And the low value of 'k' (k = 1, 2) give us small change for p^* and q^* for range of value of μ_1 and μ_2 where $\mu_{1\neq}\mu_2$, in this case when μ_1 or μ_2 changes the variation of p^* and q^* is not smooth as required. For k = 4 give us a good degree variation for p^* and q^* values. In this case μ_1 and μ_2 has a remarkable effect on choosing the best path. For instance, if in the best path $\mu_1 = 3$ (fair) and in the worst path $\mu_2 = 1$ (bad) then probability for choosing the best path is $p^* = q^* = 80\%$.



$A(\mu_1, \mu_2)$, k=1

μ_2 / μ_1	1	2	3	4	5
1	∞	1.5	1.17	1.08	**1.05**
2		∞	1.67	1.25	1.13
3			∞	1.75	1.3
4				∞	1.8
5					∞

$A(\mu_1, \mu_2)$, k=2

μ_2 / μ_1	1	2	3	4	5
1	∞	2	1.33	1.17	**1.1**
2		∞	2.33	1.5	1.27
3			∞	2.5	1.6
4				∞	2.6
5					∞

$A(\mu_1, \mu_2)$, k=3

μ_2 / μ_1	1	2	3	4	5
1	∞	2.5	1.5	1.25	**1.15**
2		∞	3	1.75	1.4
3			∞	3.25	1.9
4				∞	3.4
5					∞

$A(\mu_1, \mu_2)$, k=4

μ_2 / μ_1	1	2	3	4	5
1	∞	3	1.67	1.33	**1.2**
2		∞	3.67	2	1.53
3			∞	4	2.2
4				∞	4.2
5					∞

$A(\mu_1, \mu_2)$, k=10

μ_2 / μ_1	1	2	3	4	5
1	∞	6	2.67	1.83	**1. 5**
2		∞	7.67	3.5	2.33
3			∞	8.5	4
4				∞	9
5					∞

$A(\mu_1, \mu_2)$, k=100

μ_2 / μ_1	1	2	3	4	5
1	∞	51	17.7	9.3	**6**
2		∞	67.7	26	14.3
3			∞	76	31
4				∞	81
5					∞

Figure 13 Best response probability p* and q* as a function of MOS in both paths, for several value of k.

Finally, applying equation (28) and (29) in equation (27) to obtain equation (30), which it used to represents the utilities obtained by players to the MOS measured in each path when user are playing their best strategies, which is related to equation (28).

$$U_1^*(\mu_1, \mu_2) = U_2^*(\mu_1, \mu_2) = (2\,.\,(A(\mu_1, \mu_2) + 1).\,p^* - 2\,.\,A(\mu_1, \mu_2)\,.\,p^{*2} \qquad (30)$$

In case of want to have a remarkable improvement for both players when they select different paths instead of selecting the same paths, should assign $\mu_1 = 4$ (good) for the best path and $\mu_2 = 2$ (fair) for the worst path, then by applying this value in equation (29), we obtain A=2 and by applying it in the matrix utilities of equation (26) we obtain the following matrix:

$$M_{utilities} = \begin{pmatrix} (1,1) & (3,2) \\ (2,3) & (0,0) \end{pmatrix}$$

According to equation (28), a mixed strategy Nash equilibrium will be achieved if each player chooses the best path to transmit I and P frames with probability $p^* = q^* = 75\%$, and probability of choosing the worst path is 25% of the time. Since the expected utility for each user is $U_1^* = U_2^* = 1.5$. So regarding to this value we have an excellent improvement of 50% in the user's utilities. But without playing the game the expected utilities for each player is $U_1 = U_2 = 1$. In this case, the users would be under the situation (a) of Figure 10, which both players would be choosing the best path with probability $p = q = 1$.

6. Simulation

This chapter gives an overview about simulation tool, statement of simulation and the results of our simulations in different scenarios. The first section gives description about open source Network Simulator (NS-2), which we used to analyze the performance of our framework. The second section presents our scenarios and network features used to implement the simulations. Finally the results of each scenario are mapped in the last section.

6.1. Simulation tool

The Network Simulator 2 (NS-2) is a discrete event network simulator targeted at networking research. NS provides a packet level simulation over a lot of protocols, supporting several forms of unicast and multicast protocols including TCP and UDP transport protocols among many others, wired networking, several ad-hoc routing protocols and propagation models, data broadcasting, satellite and so on [48]. Also, NS-2 has the possibility of using mobile nodes. The mobility of these nodes may be specified either directly in the simulation file or by using a mobility trace file. Hence it is heavily used in ad hoc networking research and has become popular in research due to its open source model and online documentation.

NS began as a variant of the REAL network simulator in 1989 and has evolved substantially over the past few years. In 1995 NS development was supported by DARPA through the VINT [49], a collaborative project at LBNL (Lawrence Berkeley National Laboratory), Xerox PARC (Xerox Palo Alto Research Center), UCB (University of California, Berkeley), and USC/ISINS (University of Southern California's Information Sciences Institute). NS was built in C++ and provides a simulation interface through OTCL, an object-oriented dialect of TC (Tool Command Language). The user describes a network topology by writing OTCL scripts, and then the main NS program simulates that topology with specified parameters. Moreover, NS2 is easily extensible since the simulation kernel source code is available, which allows to implement new routing protocols, propagation models and so on, and use them in simulations.

The NS-2 simulator has been continuously updated from the contributions of many scientific and research working groups. In this work we used NS-2 version 2.27 on Ubuntu version 10.04 (32 bits) operating system. The last released version of this network simulator is NS-2.35 (Nov 4 2011). This simulator was chosen to be used in this work in order to implement the simulations and filtering the simulation results of non game and game-theoretic approach in the MANET scenario.

6.2. Description of simulations

This section aims to present the scenarios and network features used to implement the simulations. As many empirical works, an initial configuration was firstly proposed and gradually was fitted using trial and error method in order to adjust to MANET environments as accurate as possible.

Based on game-theory, two scenarios (s1 and s2) have been implemented during simulations process in order to analyze the performance of proposed schemes. As shown in the table 2, both scenarios running under same conditions and simulation settings. Both scenarios (s1 and s2) consist of set of 50 moving nodes distributed in a $500\mathrm{x}500\mathrm{m}$ Ad Hoc network with the transmission range of 80m. The speed of the moving nodes are up to $2\mathrm{m/s}$. and simulation time is fixed to $200\mathrm{s}$ for both scenarios. The video flows are transmitted from sources to destination (the number of video sources are varies from 2 to 5). In this way, the paths that discovered by MMDSR approach are same for all sources and classified equally. Each player plays routing game to select the forwarding path for each iteration of multipath routing algorithm. Since I and P frames are send through the best path with a certain probability p^* that is computed by the source nodes in each iteration.

The first scenario (s1) is based on the fixed P value, which I and P frame are sent through one of the best paths with probabilities $p^* = q^* = 0.55, 0.65, 0.75, 0.85, 0.95$ at every moment of time. In this way, we did sets of simulations for each of fixed P value and we obtained different and remarkable result for each value of P. And in the second scenario (s2), which is based on variable P value, p^* are varies according to the state of the network (MOS), where it calculated by equation (28). In this scenario p^* are varies from 0.5 to 1. In the other hand in case of game theory is disable, I and P frames are always sent through the best available path so the probability of choosing the best path is $\mathrm{p{=}q{=}1}$. The results of these simulations are mapped in the next section, which is demonstrated the preference of game theory with variable P over game theory with fixed P. At the end of simulation for different number of video sources we obtained the average losses for I, P and B frames, average delay jitter, the average end to end delay and the average packet losses for each video transmission between two nodes.

Area	500x500m
Number of nodes	50
Average node speed	2 m/s
Transmission range	80 m
Mobility pattern	Random waypoint
MAC specification	IEEE 802.11e
Nominal bandwidth	11 Mbps
Simulation time	200 s
Video codification	MPEG-2 VBR
Video bit rate	150 Kbps
Video source	2 to 5
Video	Blade Runner
Routing protocol	g-MMDSR
Transport protocol	RTP/RTCP/UDP
Maximum packet size	1500 bytes
Multipath scheme	K=3 paths
Weight parameters	1/7
Queue sizes	50 packets
Channel noise	-92 dBm

Table 2 Simulation setting for scenario s1 and s2

6.3. Simulation results

In this section we obtained our results from analyzing simulations in NS-2 environment. These simulations results represent the benefit of using the game theory technique in different situation over non game theory technique and also preference of using P as a variable value in game theory than using it as a fixed value.

Over 600 simulations have been run in order to carry out the following evaluation, without considering another hundred simulations that used to test the implemented scenario and network. These results obtained from each video transmission between two nodes in the network, which it consist of the average losses of each I, P and B frames, the average packet losses, the average end to end delay and the average delay jitter. These parameters have been measured for different number of sources, which it varies from 2 to 5, without game theory technique and with game theory technique where the P value is fixed or variable (s1 and s2).

6.3.1. Performance evaluation as a function of video sources

In the following simulations the numbers of sources increased from 2 to 5 and the CBR rate decreased from 1000000 bps to 300000 bps between source and destination, in order to simulate the congested network. The CBR traffic is sent to constrain the paths.

6.3.1.1. Two video sources

The following tables show the average results of the simulations for two video sources with CBR traffic 1000000 bps.

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
P=q=1	31.178	29.237	71.363	3.4519	51.853	1845.3

Table 3 Average losses of non-game theory for two sources (N=2)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
Variable p	1.5198	1.1803	50.029	3.0164	26.67692	1661.4

Table 4 Average losses of game theory with variable 'p' for two sources (N=2)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
0.55	6.36564	4.711944	59.70573	1.133898	35.15898	1837.493
0.65	5.03304	4.80562	59.49035	2.225153	33.21182	1544.308
0.75	2.632158	2.1733	54.90145	1.393656	29.92454	1585.81
0.85	12.34582	11.25995	63.85639	2.776482	38.2521	1262.255
0.95	7.758536	6.43282	62.51756	1.950051	36.5117	1396.126

Table 5 Average losses of game theory with fixed 'p' for two sources (N=2)

Figure 14 - 16 represent the average delay jitter, average end to end delay and the average packet losses of table 5, where the game theory technique is enabled and the value of p is fixed.

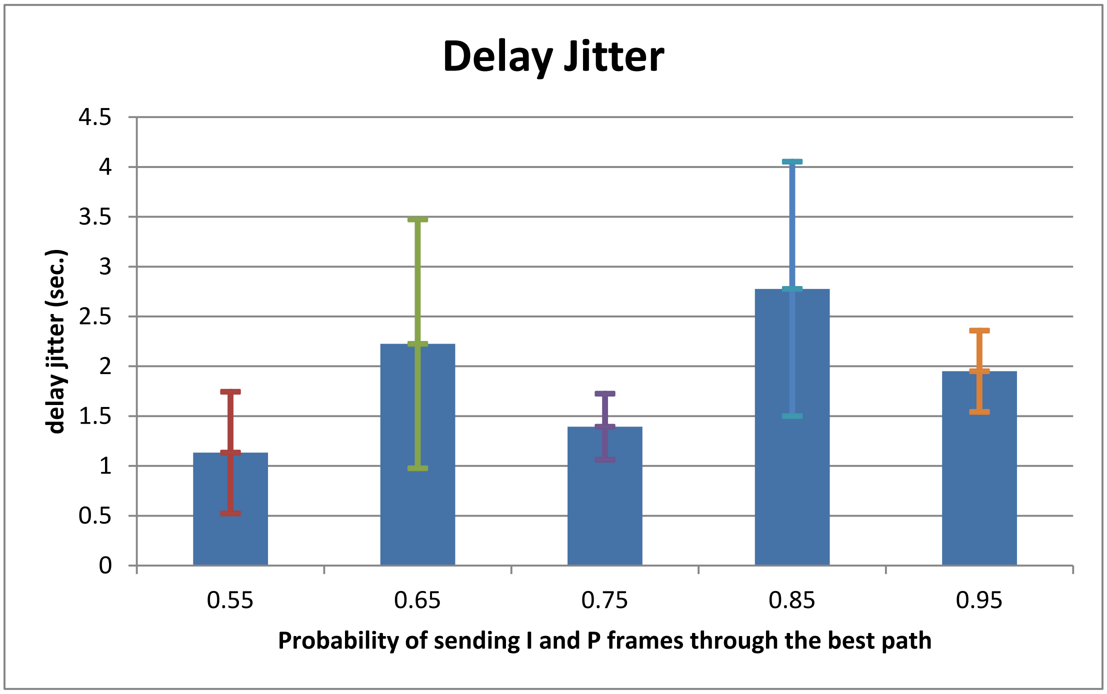


Figure 14 Average delay jitter of game theory technique with fixed P value, N=2

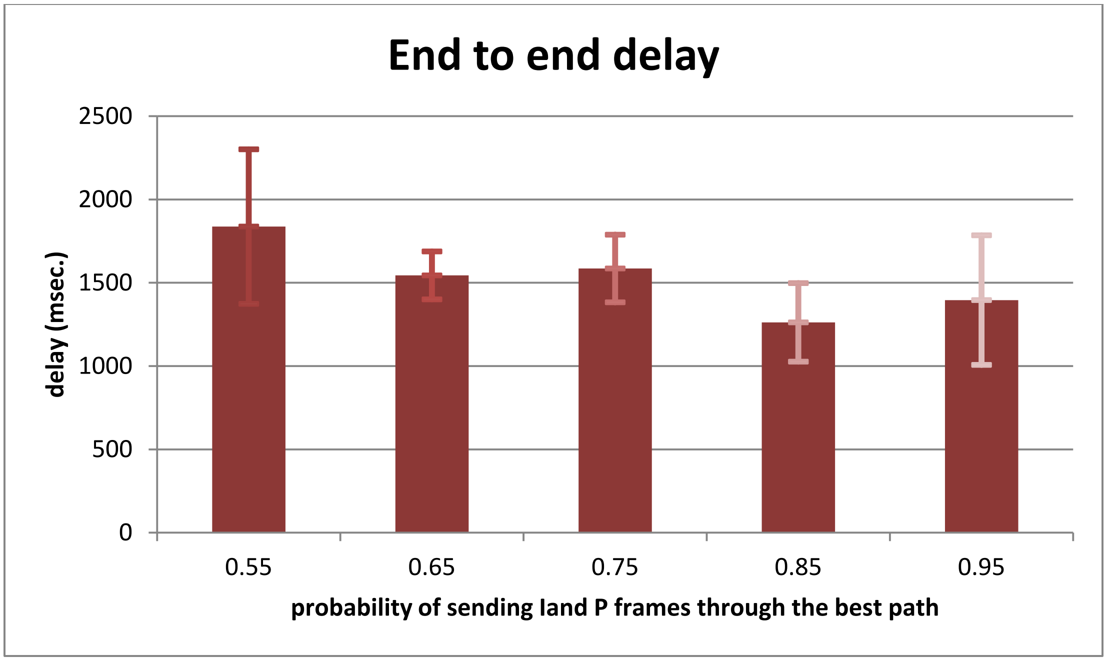


Figure 15 Average end to end delay of game theory technique with fixed P value, N=2

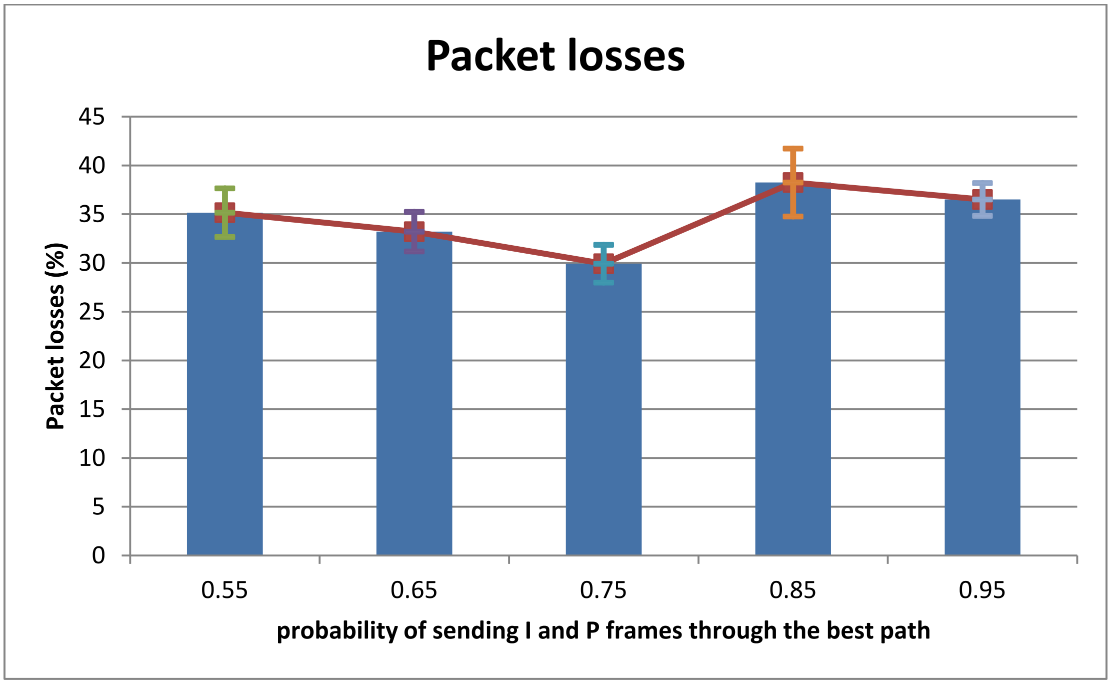


Figure 16 Average packet losses of game theory technique with fixed P value, N=2

In Figure 14 the value of average delay jitter as a function of probability of sending I and P frames through the best path is shown. The five columns are illustrated in order to corroborate the network performance for each P value. The less time and low standard error in packet delay jitter implies to higher performance of the network. So the p=0.75 shows the best performance in packet delivery variation.

Figure 15 shows the average end to end delay between two nodes as a function of probability of sending I and P frames through the best path. This figure indicates similar behaviors for all five P values considering delay jitter and standard error.

Figure 16 shows the average packet losses for each P value in game theory technique. As we already proved in section 5.5. equation (28), the best outcome comes from the less percentage of packet losses which is concern to P=0.75. Since, the best result with two sources of video in game theory technique with fixed P value is concern to P=0.75.

The following figure shows the comparison between non game theory and game theory with fixed P value.

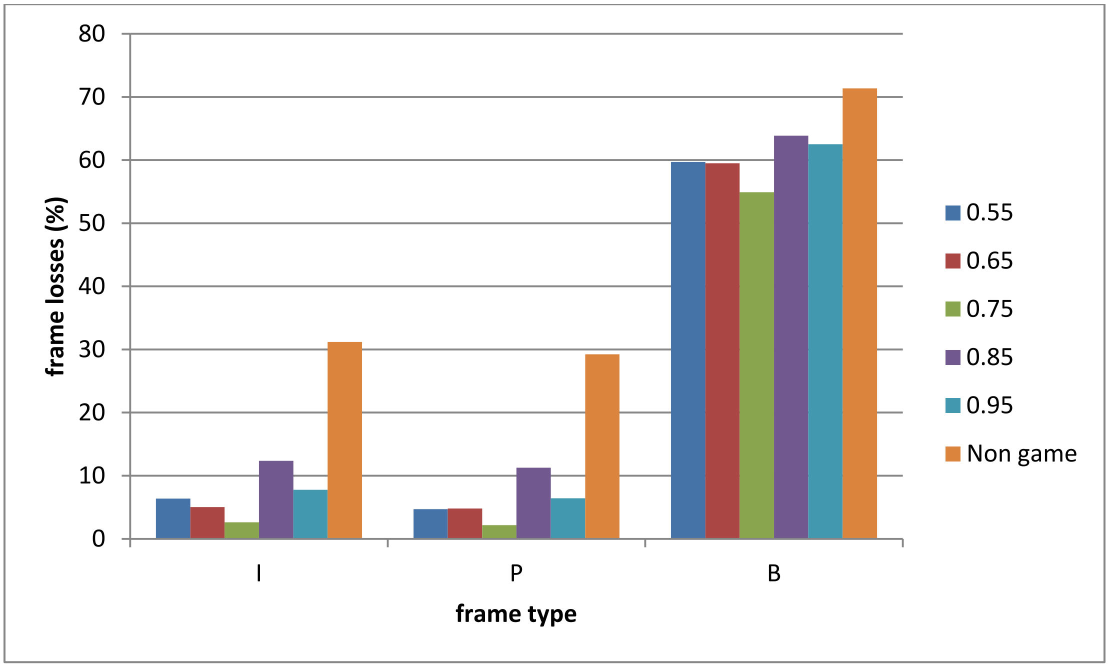


Figure 17 Average I, P and B frames losses for non game theory and game theory with fixed P value, N=2

Figure 17 shows the average percentage of frame losses in non game theory and game theory with fixed P value. It can be seen how including the game theoretic routing scheme, the average losses for I and P frames are reduced, whereas B frame do not experiment quite enhance as they are not involved in the game and always send through the worst path.

The following figure shows the comparison between two scenarios (s1 and s2).

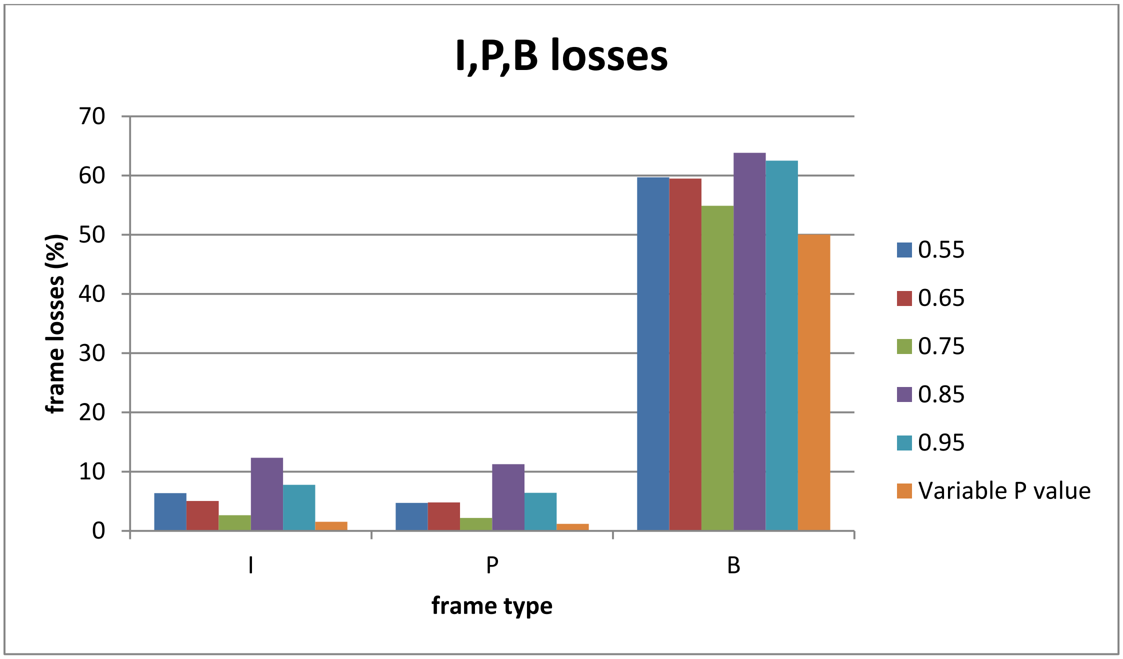


Figure 18 Average I, P and B frames losses for game theory with fixed and variable P value, N=2

Figure 18 shows the average percentage of frame losses of game theory with fixed and variable P value in multipath multimedia video streaming with two sources. It can be seen how including the game-theoretic routing scheme with variable P value, the average losses for I, P and B frames are reduced.

Regarding to this result, we can conclude the benefit of variable P value over fixed P value in game theory and the reference of the game theory in both scenarios over non-game theory.

6.3.1.2. Three video sources

The following tables show the average results of the simulations for three video sources with CBR traffic 700000 bps.

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
P=q=1	26.73112	5.964464	81.635156	6.2556178	52.43768	2680.827029

Table 6 Average losses of non-game theory for three sources (N=3)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
Variable p	2.541436	0.93253	78.432898	2.9639772	41.76888	2092.03178

Table 7 Average losses of game theory with variable 'p' for three sources (N=3)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
0.55	6.620594	0.583872	78.29682	3.898978	42.65322	2646.615
0.65	5.082874	0.461756	79.34421	3.758368	42.98264	2189.383
0.75	9.513812	0.131826	79.36814	3.808145	44.08756	2285.833
0.85	15.28177	2.703306	78.77283	3.140688	45.57052	2580.929
0.95	10.69613	0.96077	82.00279	2.13347	45.4695	2562.178

Table 8 Average losses of game theory with fixed 'p' for three sources (N=3)

Figure 19 - 21 represent the average delay jitter, average end to end delay and the average packet losses of table 8, where the game theory technique is enabled and the value of p is fixed.

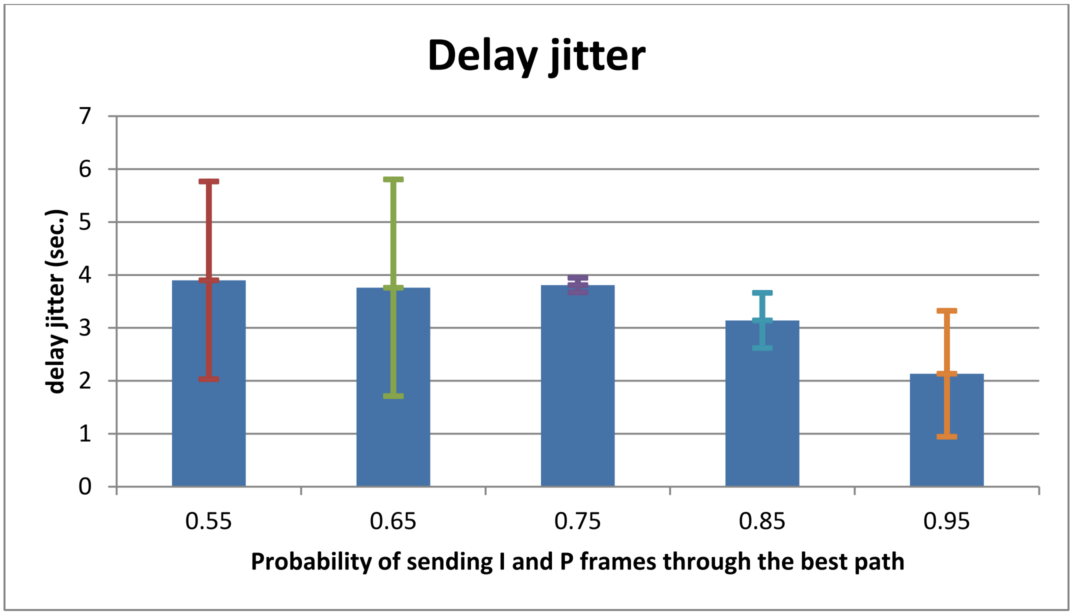


Figure 19 Average delay jitter of game theory technique with fixed P value, N=3

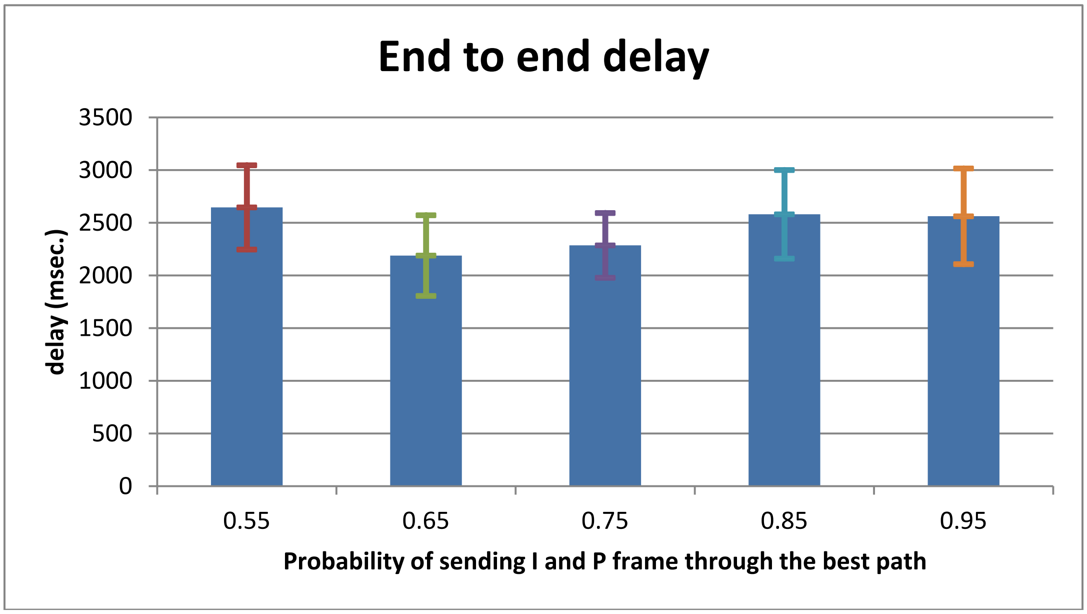


Figure 20 Average end to end delay of game theory technique with fixed P value, N=3

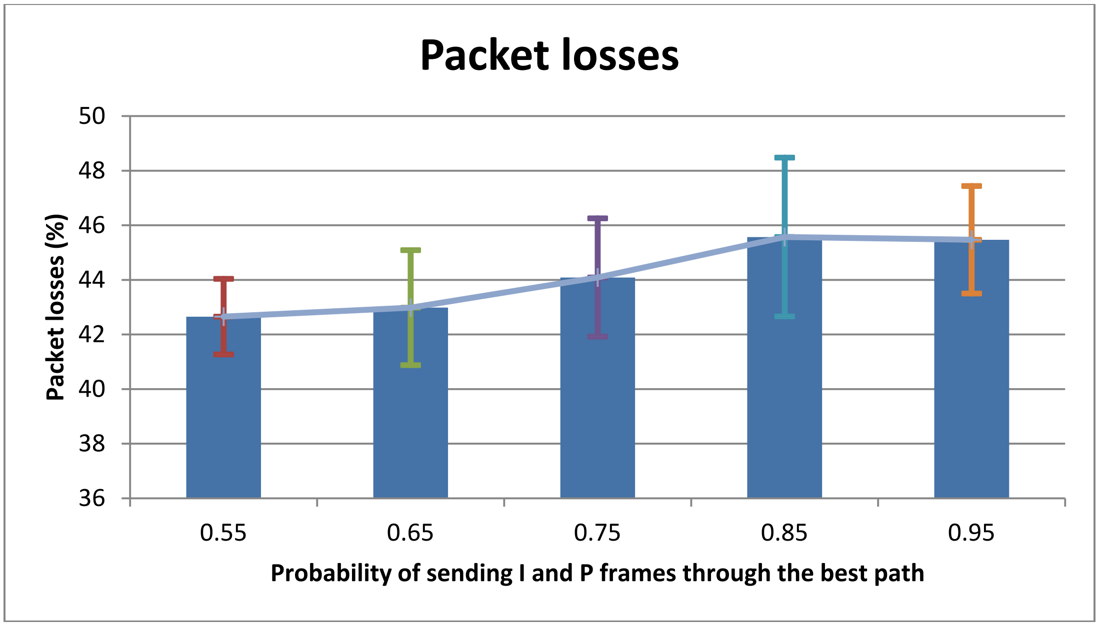


Figure 21 Average packet losses of game theory technique with fixed P value, N=3

In Figure 19 the value of average delay jitter as a function of probability of sending I and P frames through the best path is shown. The five columns are illustrated in order to corroborate the network performance for each P value. The less time and low standard error in packet delay jitter implies to higher performance of the network. In this case, all value of p almost has a same delay jitter in three video sources and its delay jitter comparing to non game theory is reduced.

Figure 20 shows the average end to end delay between two nodes as a function of probability of sending I and P frames through the best path. This figure indicates similar behaviors for all five P values considering delay jitter and standard error. The end to end delay for all value of p is almost same.

Figure 21 shows the average packet losses for each P value in game theory technique. In the three video sources, we have less losses in p = 0.55 and 0.65 comparing to others p value, because the number of users increased so the congestion for sending I and P frame through the best path increased too. So, the best result meet when I and P frame send through the best path with lower probability than before.

The following figure shows the comparison between non game theory and game theory with fixed P value.

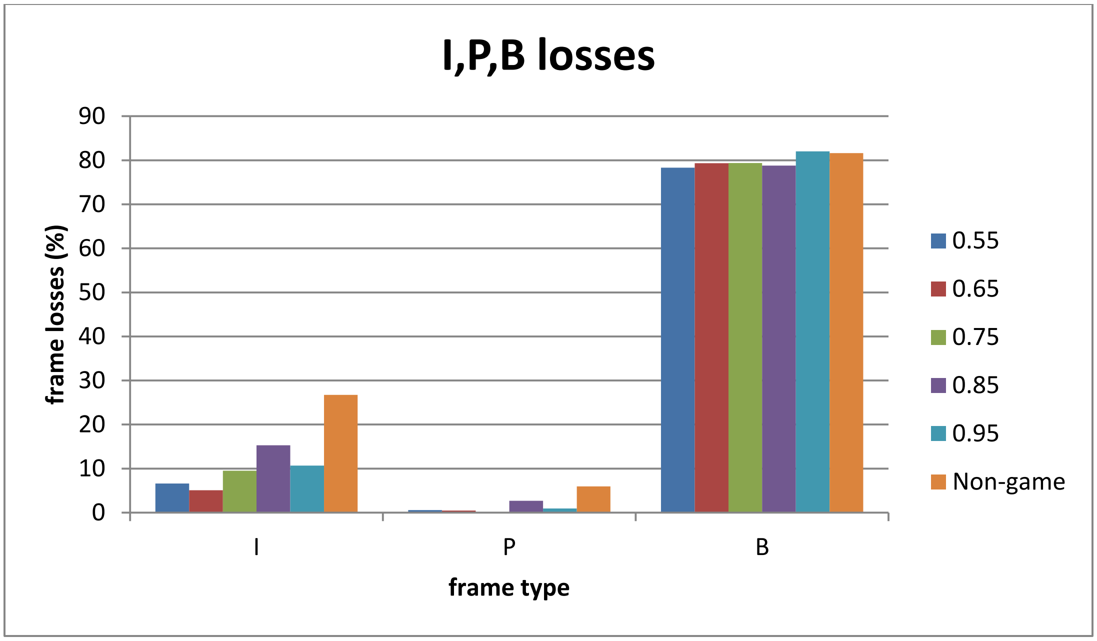


Figure 22 Average I, P and B frames losses for non game theory and game theory with fixed P value, N=3

Figure 22 shows the average percentage of frame losses in non game theory and game theory with fixed P value. It can be seen how including the game theoretic routing scheme with three video sources, the average losses for I and P frames are reduced, whereas B frame do not experiment quite enhance as they are not involved in the game and always send through the worst path.

The following figure shows the comparison between two scenarios (s1 and s2).

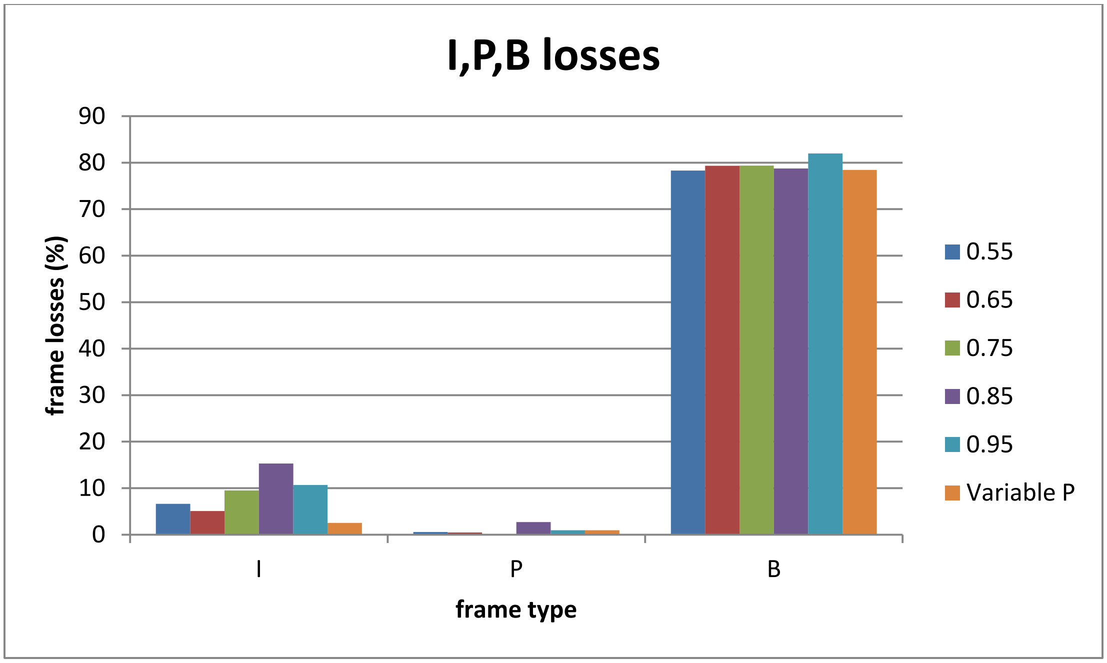


Figure 23 Average I, P and B frames losses for game theory with fixed and variable P value, N=3

Figure 18 shows the average percentage of frame losses of game theory with fixed and variable P value in multipath multimedia video streaming with three sources. It can be seen how including the game-theoretic routing scheme with variable P value, the average losses for I, P and B frames are reduced.

Regarding to this result, we can conclude the benefit of variable P value over fixed P value in game theory and the reference of the game theory in both scenarios over non-game theory even with three video sources.

6.3.1.3. Four video sources

The following tables show the average results of the simulations for four video sources with CBR traffic 500000 bps.

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
P=q=1	11.730846	0.89029	82.342658	1.1455524	44.59988	23629.84918

Table 9 Average losses of non-game theory for four sources (N=4)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
Variable p	1.573128	0.407376	88.759162	0.8520726	43.03844	24205.31616

Table 10 Average losses of game theory with variable 'p' for four sources (N=4)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
0.55	3.77716	0.331568	87.78619	3.034074	43.53078	22685.17
0.65	3.55694	0.369748	84.15001	0.519055	41.57266	23263.81
0.75	3.164344	0.85729	85.99323	0.942373	40.527	28823.3
0.85	3.253804	0.521166	81.497	2.183241	43.9934	15036.49
0.95	3.275768	0.956674	81.72824	4.637219	39.97016	22582.88

Table 11 Average losses of game theory with fixed 'p' for four sources (N=4)

Figure 24 - 26 represent the average delay jitter, average end to end delay and the average packet losses of table 11, where the game theory technique is enabled and the value of p is fixed.

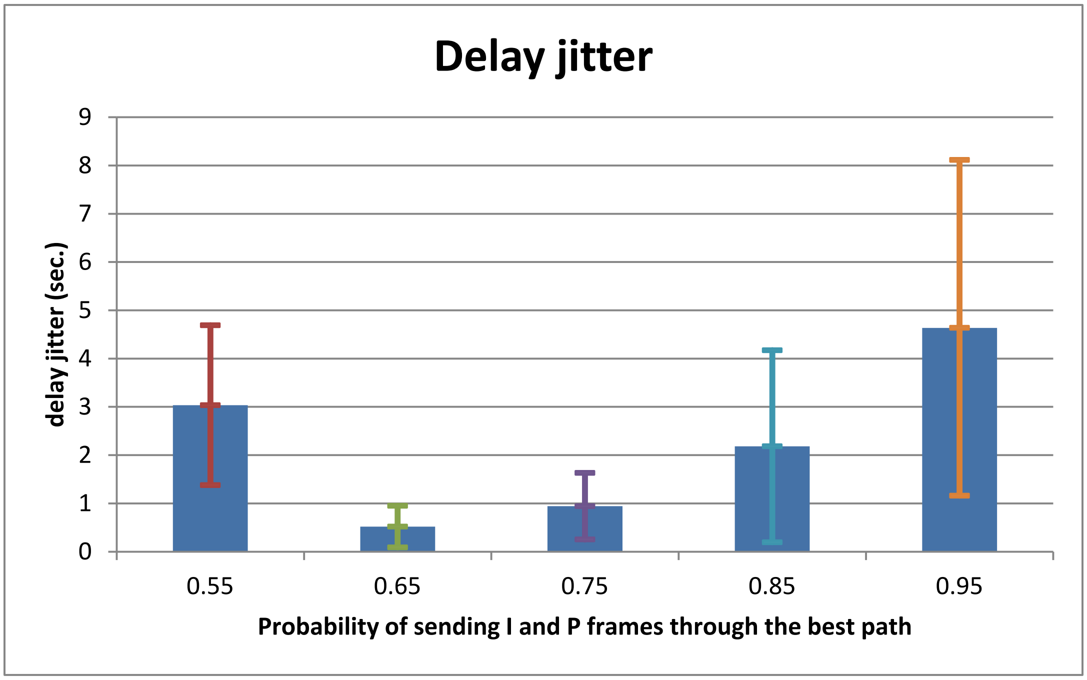


Figure 24 Average delay jitter of game theory technique with fixed P value, N=4

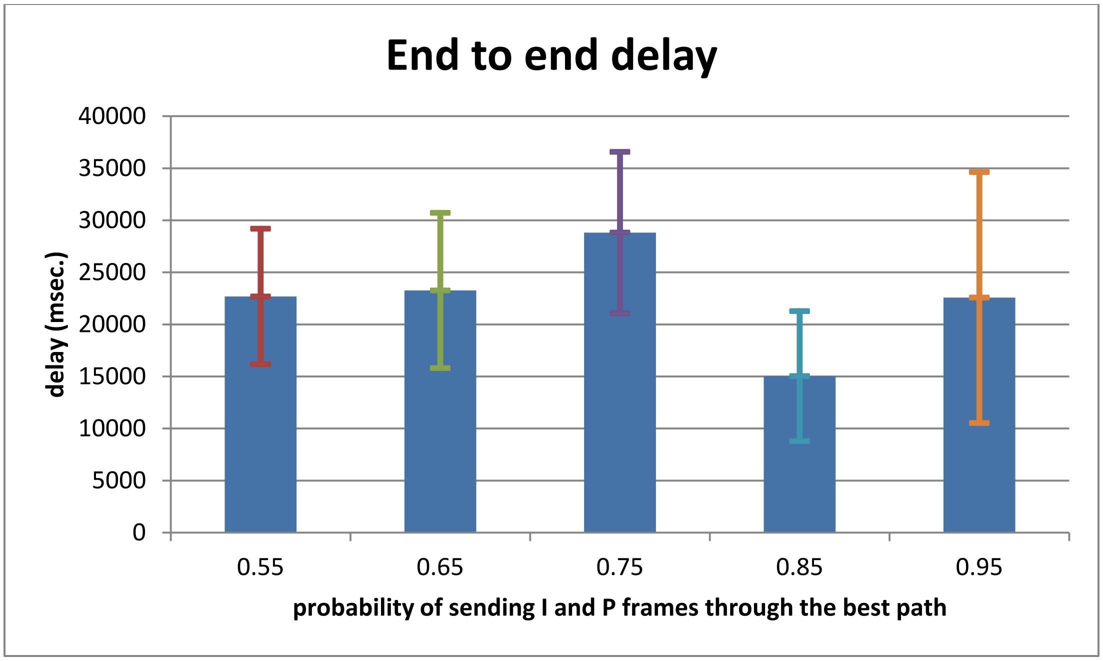


Figure 25 Average end to end delay of game theory technique with fixed P value, N=4

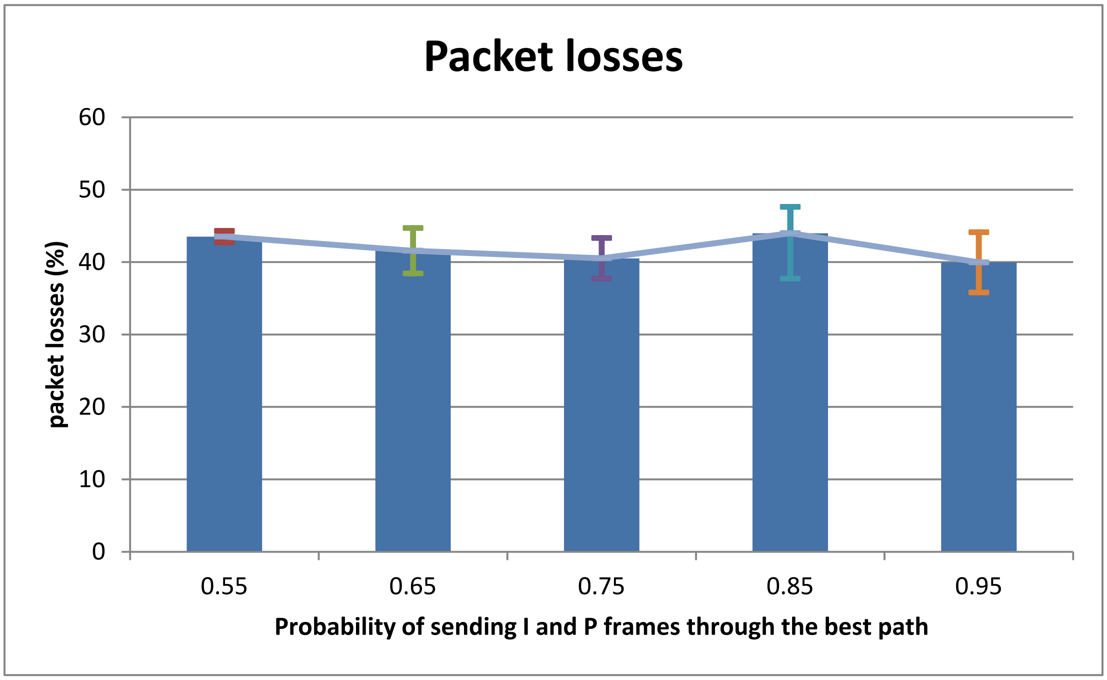


Figure 26 Average packet losses of game theory technique with fixed P value, N=4

In Figure 24 the value of average delay jitter as a function of probability of sending I and P frames through the best path is shown. The five columns are illustrated in order to corroborate the network performance for each P value. The less time and low standard error in packet delay jitter implies to higher performance of the network. In this case, we have small delay for p = 0.65 and p = 0.75, so the best performance in packet delivery meet with these two probability in case of four sources.

Figure 25 shows the average end to end delay between two nodes as a function of probability of sending I and P frames through the best path. This figure indicates less end to end delay for sending packet when the p = 0.85. As the number of sources increased, the end to end delay between nodes increased too. Here we have higher delays comparing to two and three sources.

Figure 26 shows the average packet losses for each P value in game theory technique. In the four video sources, we have small losses in p = 0.75 comparing to others p value, which it is not remarkable due to, increased the number of video sources. In this case all value of P almost has same losses for packets.

The following figure shows the comparison between non game theory and game theory with fixed P value.

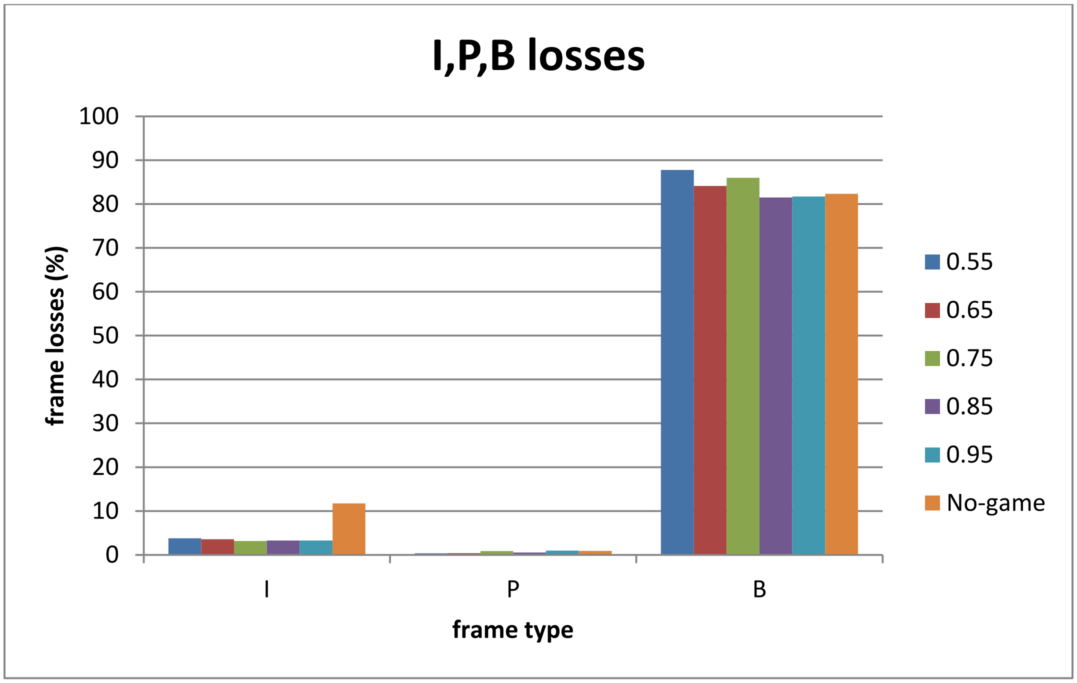


Figure 27 Average I, P and B frames losses for non game theory and game theory with fixed P value, N=4

Figure 27 shows the average percentage of frame losses in non game theory and game theory with fixed P value. It can be seen how including the game theoretic routing scheme with four video sources, the average losses for I and P frames are reduced. The average number of frame losses with probability p =0.55 – 0.95 are almost same while the average frame losses in non-game theory still higher than game theory.

The following figure shows the comparison between two scenarios (s1 and s2).

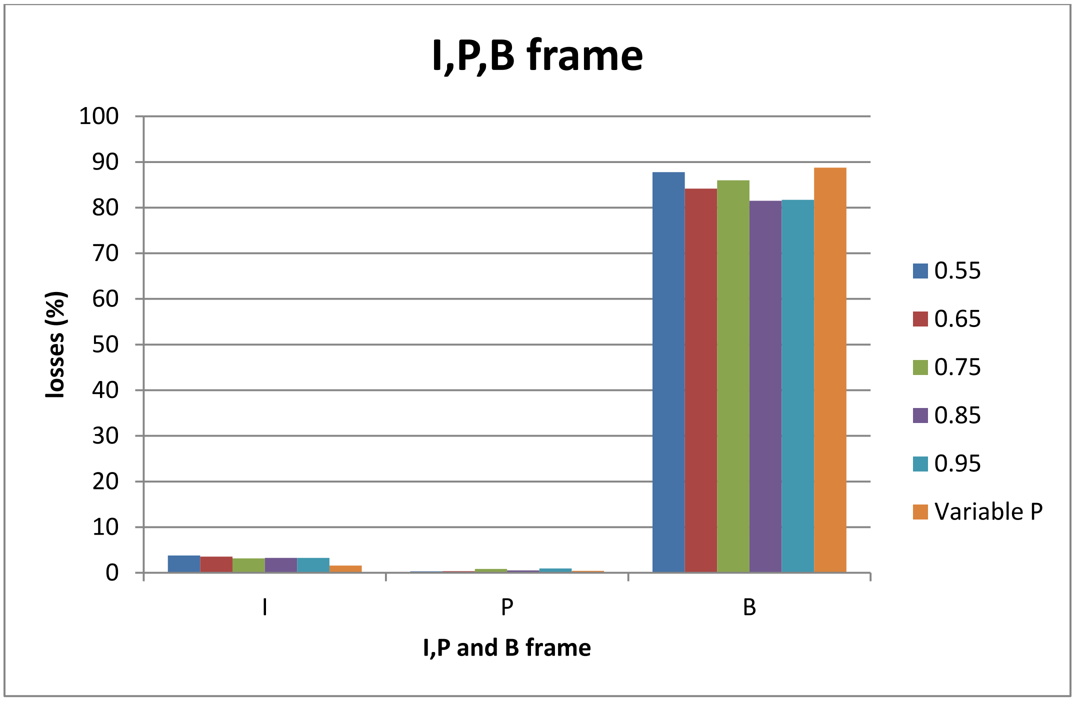


Figure 28 Average I, P and B frames losses for game theory with fixed and variable P value, N=4

Figure 28 shows the average percentage of frame losses of game theory with fixed and variable P value in multipath multimedia video streaming with four sources. It can be seen how including the game-theoretic routing scheme with variable P value, the average frame losses still reduced comparing to the game theory with fixed P value.

Regarding to this result, we can conclude the benefit of variable P value over fixed P value in game theory and the reference of the game theory in both scenarios over non-game theory even with four video sources.

6.3.1.4. *Five video sources*

The following tables show the average results of the simulations for five video sources with CBR traffic 300000 bps.

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
P=q=1	23.493194	0.850214	87.509926	2.9118796	54.20234	6437.87701

Table 12 Average losses of non-game theory for five sources (N=5)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
Variable p	3.64812	1.258078	90.833736	0.5137356	47.65712	14340.30895

Table 13 Average losses of game theory with variable 'p' for five sources (N=5)

	I (%)	P (%)	B (%)	Delay jitter (sec.)	Losses (%)	Delay (msec.)
0.55	6.384946	3.01902	85.26902	0.534203	50.7687	9515.695
0.65	12.77014	2.659814	83.76208	1.715514	52.47128	5122.636
0.75	11.45766	1.041388	91.07702	0.486443	51.12948	13133.06
0.85	10.93539	1.26021	92.5114	0.667249	51.60316	3496.647
0.95	11.75736	4.422312	91.55767	0.665708	54.46682	2934.772

Table 14 Average losses of game theory with fixed 'p' for five sources (N=5)

Figure 29 - 31 represent the average delay jitter, average end to end delay and the average packet losses of table 14, where the game theory technique is enabled and the value of p is fixed.

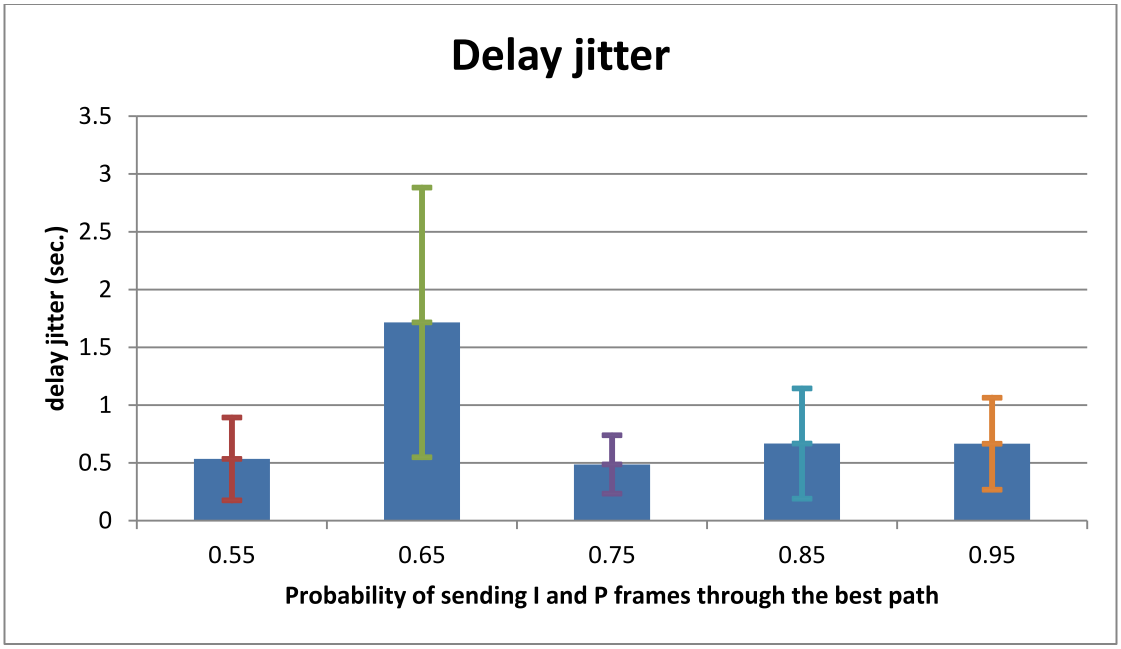


Figure 29 Average delay jitter of game theory technique with fixed P value, N=5

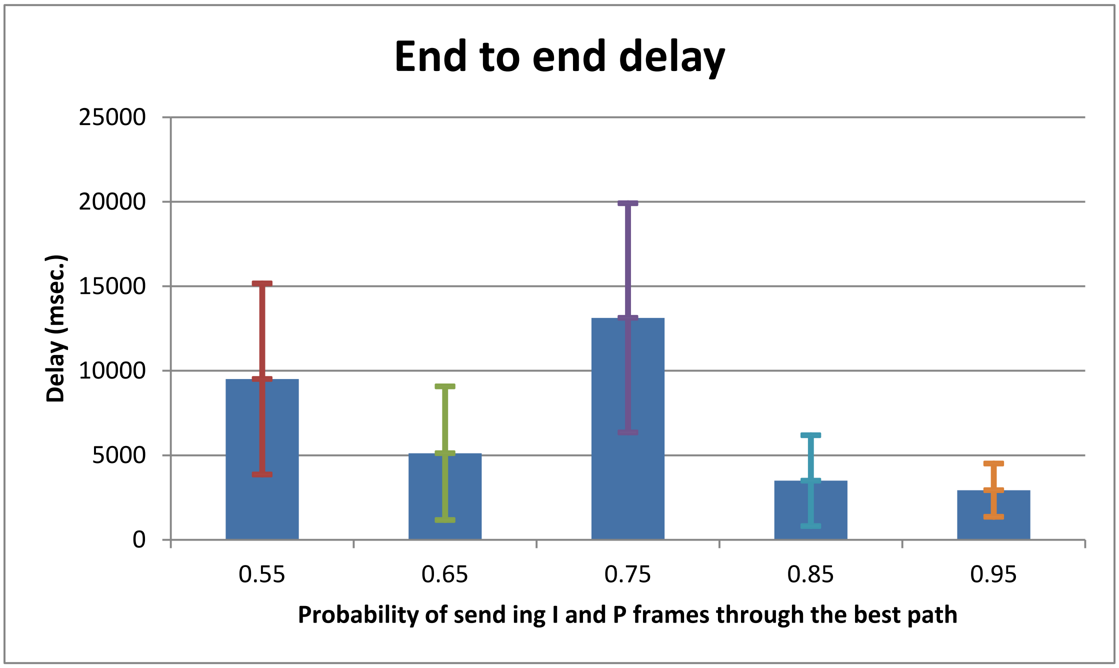


Figure 30 Average end to end delay of game theory technique with fixed P value, N=5

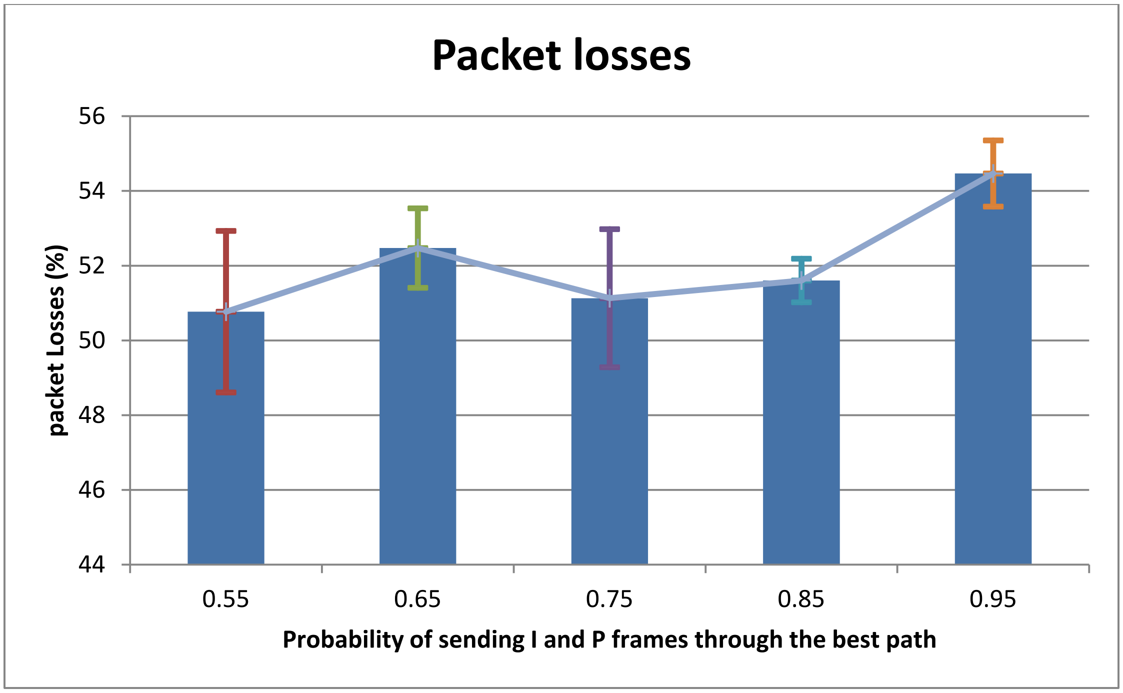


Figure 31 Average packet losses of game theory technique with fixed P value, N=5

In Figure 29 the value of average delay jitter as a function of probability of sending I and P frames through the best path is shown. The five columns are illustrated in order to corroborate the network performance for each P value. The less time and low standard error in packet delay jitter implies to higher performance of the network. In this case, almost all value of P has same delay jitter except p = 0.65, which it has higher delay jitter comparing to others in the five video sources.

Figure 30 shows the average end to end delay between two nodes as a function of probability of sending I and P frames through the best path. This figure indicates less end to end delay for sending packet when the p = 0.85 and 0.95.

Figure 31 shows the average packet losses for each P value in game theory technique. In the five video sources, we have small losses in p = 0.55 comparing to others p value, which it is not remarkable due to, increased the number of video sources. In this case all value of P almost has same losses for packets.

The following figure shows the comparison between non game theory and game theory with fixed P value.

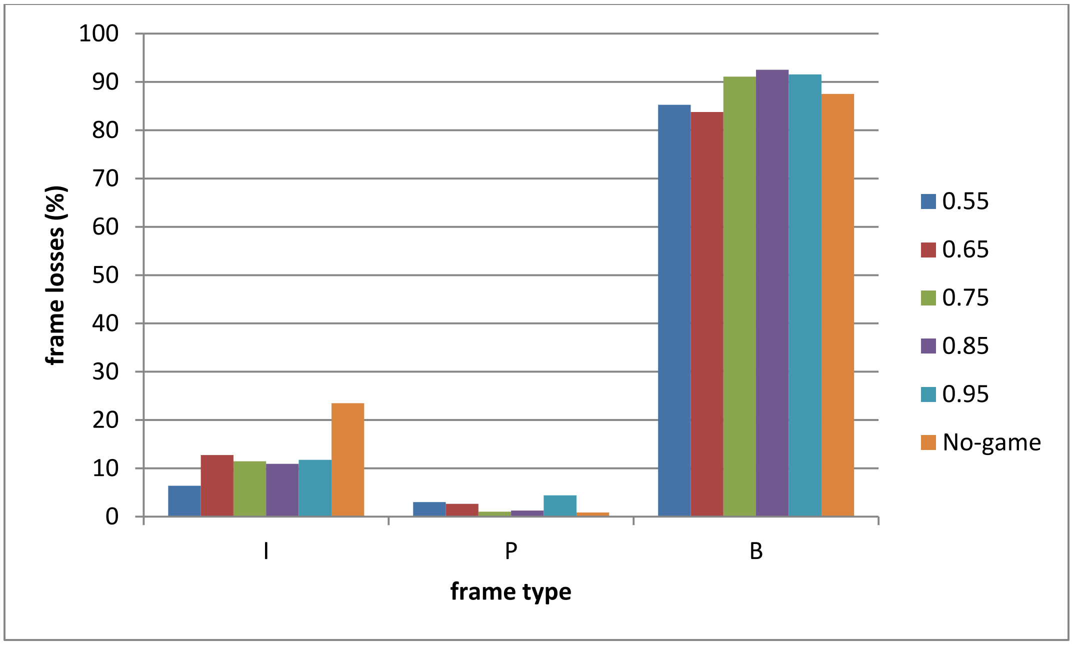


Figure 32 Average I, P and B frames losses for non game theory and game theory with fixed P value, N=5

Figure 32 shows the average percentage of frame losses in non game theory and game theory with fixed P value. It can be seen how including the game theoretic routing scheme with five video sources, the average losses for I and P frames are reduced. The average number of frame losses with probability p =0.55 – 0.95 are almost same while the average frame losses in non-game theory still higher than game theory.

The following figure shows the comparison between two scenarios (s1 and s2).

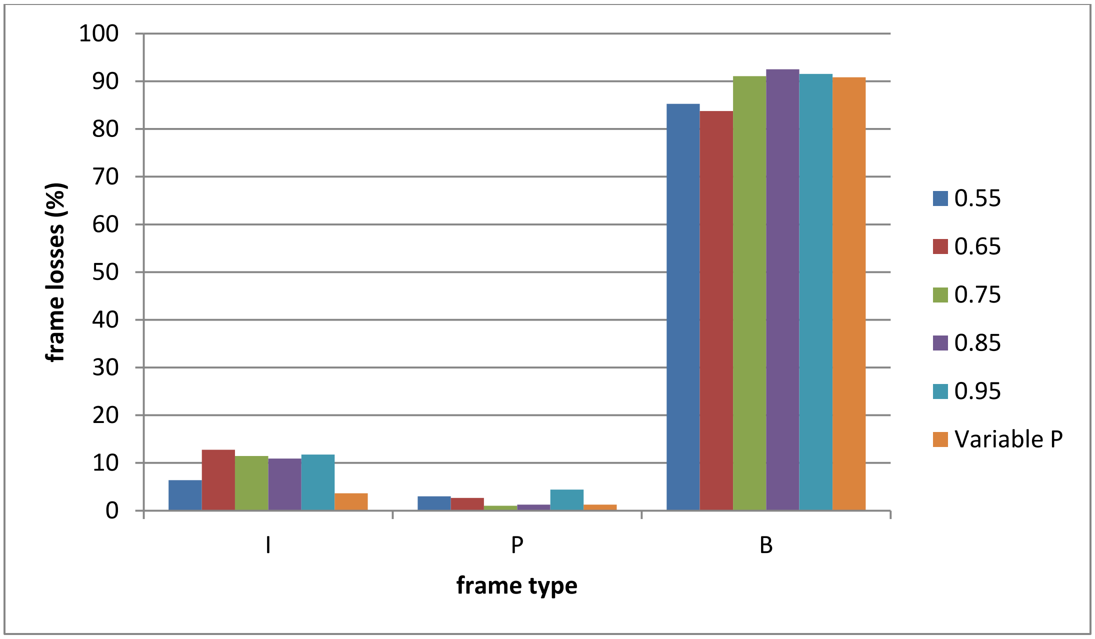


Figure 33 Average I, P and B frames losses for game theory with fixed and variable P value, N=5

Figure 33 shows the average percentage of frame losses of game theory with fixed and variable P value in multipath multimedia video streaming with five sources. It can be seen how including the game-theoretic routing scheme with variable P value, the average frame losses still reduced comparing to the game theory with fixed P value.

Regarding to this result, we can conclude the benefit of variable P value over fixed P value in game theory and the reference of the game theory in both scenarios over non-game theory even with five video sources.

All of these simulations indicated that with increasing the number of video sources the frame losses increased too but still prove the benefit of scenario 1 over scenario 2 and in total preference of the game theory technique over non-game theory.

7. Conclusion and Future lines

As discussed earlier due to the inherent features of the wireless Ad Hoc networks, providing video streaming over this type of networks is one of the challenging issues. In this work, we analyzed an extension of DSR protocol, named g-MMDSR (game-theoretic Multipath Multimedia Dynamic Source Routing) over Mobile Ad Hoc networks. This extension includes a game-theoretic approach over QoS-aware self-configured multipath routing scheme, which users can involve and decide in the resource allocation procedure. In this way, users start the strategic routing game, which they send the most important video frames (I and P frames) through one of the two best paths according to certain probability instead of sending these frames through the best path. Also, the multipath routing protocol configures itself dynamically according to the state of the network because of the features of the wireless Ad Hoc networks.

Two scenarios of game-theoretic scheme have been evaluated, which the first one was concern about the sending I and P frames through the path with the fixed probability at the moment of time and in the second scenario we examine path when we send the I and P video frames through one of the best path with the variable probability according to the state of the networks.

The simulation result show the benefits of the game theoretic compared to the case when users do not play the game scheme. Also shows benefits of game theory with variable P over fixed P. It increases the efficiency of the network and the degree of the satisfaction of the users with decreasing the number of frame losses.

As future line, we can apply this framework to the other wireless Ad Hoc networks such as VANETs (Vehicular Ad Hoc Networks), in which passenger of the vehicle can streaming the video during the traveling. Also it would be interesting to apply this framework from two players to N-players with more accuracy, so we must finding an equation for N-players instead of only two players.

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