MOBILE AD-HOC COMMUNICATIONS IN AEC INDUSTRY

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EDITOR: D. Rebolj and K. Menzel

Koojana Kuladinithi
ComNets, University of Bremen, Germany
email: kuladinithi@ikom.org

Andreas Timm-Giel
ComNets, University of Bremen, Germany
email: atg@comnets.uni-bremen.de

Carmelita Görg
ComNets, University of Bremen, Germany

SUMMARY*: Wearable computing along with advanced mobile communication has the potential to revolutionise the working environment and working processes of the mobile worker of the AEC industry. While wearable computing allows the mobile worker to execute his/her work and tasks more efficiently and safer with the support of information provided by novel user interfaces, like augmented reality glasses and voice recognition, advanced mobile communication can transfer the information required in a certain context (location, time, task etc.) to and from the mobile worker. Wearable computing allows the mobile worker e.g. to access data bases like material lists and CAD drawings, to hold video conferences with remote or on-site experts without being distracted by additional hardware he has to handle, i.e. his hands and arms are free to concentrate completely on his work. For transferring data and voice calls numerous different networking technology and communication networks are available, like GPRS, UMTS and WLAN. However, communication costs, bandwidth and coverage limitations might prohibit its use on construction environments. Ad-hoc networking offers means of spontaneous communications between different devices without using an infrastructure and provides a promising communication solution for the AEC industry. This article focuses on the applicability of mobile ad-hoc networking in the AEC industry by providing a detailed scenario of how mobile ad-hoc networking can be used in the AEC industry, giving an overview of the existing mobile ad-hoc networks and addressing some issues of implementation and deployment of the networking protocol called Ad-hoc On-demand Distance Vector routing (AODV).*

KEYWORDS: *AEC, wearable computing devices, infrastructure-less communication, AODV*

1. INTRODUCTION

The development and use of small computing devices that can be part of an individuals clothing has laid the foundation for a new way of using computers, namely Wearable Computing (Crabtree et al, 1998). Imagine how a worn computer with advanced, embedded audio visual interfaces can improve the efficiency and the effectiveness of a field based worker such as a field technician, an emergency medical worker or a factory worker, with access to information (audio, video or data) he/she requires. A technician can have video conferences with office based experts or colleagues, to obtain advice or provide such advice. They can have access to information residing anywhere in the world. These workers can even operate these devices while on the move to and from or while moving within the operational sites. Connectivity between personnel, especially at a place like a construction site, should be expected to work, even in situations where basic networking infrastructure such as cabling or wireless access points, is not available. Ad-hoc networking is one approach to provide communication between devices in this environment.

Mobile ad-hoc networks (Perkins et al, 1999) consist of mobile computing devices that are formed in impromptu environments in which the users of these computing devices wish to communicate with each other. The fundamental nature of these networks is that communications are done without relying on external networking infrastructure. Each device in these ad-hoc networks has some wireless communication means such as Bluetooth, WLAN (Wireless LAN), Infrared, UWB (Ultra Wide Band), etc, and is free to join or leave the network at any time. These networks get configured automatically to communicate within the formed ad-hoc network.

This article is an effort to explain the applicability of mobile ad-hoc networks in field based or similarly characterized environments that, except for the users computing device, has no access to networking infrastructure that is usually present in office based environments. The next section provides a scenario which details the usage possibilities of mobile ad-hoc networking in the daily life of a field based electrician. It further explains the existing technologies (communication, hardware and software of wearable devices) that can be used in a constructing environment. The third section gives an overview to mobile ad-hoc networks. It further explains the basic operations of one of the most widely used mobile ad-hoc networking protocols called Ad-hoc On-demand Distance Vector (AODV) routing and the penultimate section discusses the implementation and deployment issues related to AODV. The last section is the concluding summary.

2. APPLICATION SCENARIO

This section shows a vision of use (through the use of a scenario) of wireless access in the daily life of personnel involved in civil construction operations, where there is no networking infrastructure available.

2.1 Daily life of a field based electrician

An electrician at a building construction site of a shopping mall, starts his day by wearing his working jacket which is equipped with a light weight voice activated computing device. Video display, video camera, and the audio input/output headset are also connected to the computing device. The first task of this worker is to look at the schedule of work that is allocated to him for the current day on the voice activated computer’s display. The display informs him about the activities that he should perform and the location in which the services are needed. He is also informed where he should go to collect all the tools and materials required to perform his duty as specified in his schedule. While walking to the tools warehouse, he brings up the list of tools required and on what shelves these tools are available. While picking up the tools from the shelves, he informs the computer about acquiring these tools. The material list is displayed next, and the computer informs him that part of the material is on the site where the activities need to be performed but shows some items that need to be acquired from the materials warehouse. He obtains these materials and updates about acquiring them. Next, the voice activated computer displays the location information of the site where the work needs to be done. He walks up to the exact location using the instructions shown on the screen and once there, makes an assessment of the environment, to see if the prerequisites to commence his work are present. He brings up a screen on his computer that shows the piping layout as indicated in the plan.

FIG. 1: A wearable device user

His first task is to pass wiring cables to the other room and complete the basic wiring at the room. While passing cables, he starts exchanging information (e.g. length of the cable) with the co-worker at the next room. Once he completes laying cables, he updates the material usage and next the video display shows the blueprint, where the panel board should be located. He realizes that the place specified is not according to the standards and he immediately requests for a video conferencing session with his senior electrician who is located somewhere in the site, to obtain advice as to how to proceed. The senior electrician also brings up the same blueprint and they collectively decide to make a video conferencing session with the architect of the building. The architect informs that the panel board was specified for a different setup which was proposed previously, and that the location needs to be changed accordingly. Once the conference is over, he makes a request for the site officer to update about the change through an email.

While continuing to work, he receives a voice call from a junior co-worker requesting some advice on how the wiring connections are made in a smoke detection system. He requests the co-worker to activate the video camera and views what the co-worker is viewing and advises him that the left most pins should be connected to the alarm system and the rest are for the power supply.

At the end of the day, while walking back to return the tools and balance materials, he updates his work that was performed for that day and looks at the schedule for the work needed to be done for the following day. While browsing this, he checks to see what tools he requires for tomorrow and returns only the tools and balance material which are not required for tomorrow’s work, so that he does not need to return to the tool warehouse tomorrow.

2.2 Technical background

The worn jacket of the above worker is integrated with wearable devices. Video cameras and the head-set are integrated to a portable computing device. This device is the main computer that controls all the other devices, while enabling communications between them. Communications to the outside is through WLAN using mobile ad-hoc networking protocols (explained in Section 3) which belong to the Internet Protocol (IP) suite. All workers (e.g., electricians, technicians, plumbers, operators, site engineers, supervisors, etc.) at the site have at least a single wearable computing device which is capable of communicating (i.e. with the co-worker at the next room/senior electrician/junior worker, updating the material/tools usage or activity lists, sending email to the site officer) over an ad-hoc networking protocol. Once a worker requests to communicate with outside personnel (i.e. video conference with the architect), this request goes to the site office, which may be located at the container, and then it will be forwarded through the communication means available at the site office (e.g., over satellite links or fixed links).

The wearable computing environment explained in the above scenarios consists of devices, software and a mobile communication environment. Wearable devices and presenting engineering information on wearable devices (i.e. software) are one of the emerging areas of research in Mobile/Wearable Computer-Aided Engineering (CAE) systems (Crabtree et al., 1998, Garrett et al., 2002). Individual computing devices such as head mounted displays are already in use in different industries. But, the integration of these devices with networking technologies and IT based applications (e.g. voice activated applications, presenting tasks to be done, showing the technical diagram on the display) in an appropriate manner is not yet widely considered. The following section explains the state of art of existing technologies that can be applicable in the AEC industry.

Wearable devices: Head mounted displays as shown in the figure 1 might not be suitable for any working environment due to the inconvenience to wear and are bulky. There are other head mounted displays based on the Light-Guide Optical Element (LOE) technology. The LOE devices are compact and lightweight. And its optical parameters ensure a convenient and strain-free viewing experience. These devices are now available as standard glasses (www.lumusvision.com). The belt worn computers can have varying sizes ranging from a normal PDA (Personal Digital Assistant) to the size of a buckle of a belt. The core part of the QBIC wearable device is integrated in a belt buckle, which has a 400MHz processor speed and USB and WLAN connections. The batteries and connectors of other devices (e.g. head mounted display) can be integrated in the belt (Lukowicz et al, 2004).

User Interaction: In a working environment, users should be able to interact with wearable devices with comfort without distracting their work. The interacting devices should have properties such as ease of use, portability and to get reliable inputs. At the moment, the interaction between users and devices can also be done using voice activated mechanisms or glove-based keyboards like KITTY (Chen et al, 2004).

Wireless communication technologies: Wireless communication can be achieved through cellular networks of GPRS or UMTS. But, comparing the cost, coverage and the bandwidth available, cellular networks are not good enough to use for applications like file transfer or video conferencing. Mobile ad-hoc networks allow communication between workers in a cost effective manner. There is no need to provide any networking infrastructure to form an ad-hoc network. Following explains the different wireless communication technologies that can be used to form an ad hoc network between workers devices.

WLAN (IEEE 802.11): Wireless local area network operates in the 2.4 GHz and 5 GHz unlicensed ISM (Industrial, Scientific & Medical) band and uses spread spectrum technology. A wireless LAN does not require lining up devices for line-of-sight transmission like IR (Infra Red). It transmits a radio frequency over an area of several hundred meters and can penetrate walls and other non-metallic barriers.

HomeRF: The Home Frequency working group has developed a wireless technology to provide both voice and data connections between the devices in typical home environments, using Shared Wireless Access Protocol (SWAP) (Negus, 2000). In the ad-hoc mode, SWAP system supports only data communication and it utilizes same functionality like in IEEE 802.11.

HiperLAN[1]/2: The Broadband Access Network group of the European Telecommunication Standards Institute (ETSI[2] BRAN[3]) has specified the HiperLAN/2 system for high bit rate wireless communications. The main features of the HiperLAN/2 are high-speed transmission, connection oriented operation and Quality of Service (QoS) support (Johnson, 1999).

Bluetooth: The Bluetooth Special Interest Group (SIG) has developed a short-range radio technology intended to be used as a cable replacement. The essential features of the Bluetooth technology are robustness, low complexity, low power consumption, and low cost compared to others (Zurbes, 2000).

UWB (Ultra Wide Band): UWB system utilizes the unlicensed 3.1 – 10.6 GHz UWB band, as regulated in the United States. The UWB system provides a wireless PAN (Personal Area Network) with data payload communication capabilities of 55, 80, 110, 160, 200, 320, and 480 Mb/s. The support of transmitting and receiving at data rates of 55, 110, and 200 Mb/s is mandatory. The proposed UWB system employs multi-band orthogonal frequency division multiplexing (OFDM).

TABLE 1: Properties of Wireless Communication Technologies

	WLAN(802.11a/b)	***HomeRF***	***HiperLAN/2***	***Bluetooth***	***UWB***
Frequency	2.4 GHz / 5 GHz	2.4 GHz	5 GHz	2.4 GHz	3.1-10.6 GHz
Range	100 - 250 m	50 m	100 - 250 m	10 - 100 m	8 – 20 m
Bit Rate	11 / 54 Mbps	11 Mbps	54 Mbps	0.7 – 1 Mbps	55, 110 & 200 Mbps

Nature of above communication technologies and the interactions between those technologies and upper layers (routing environment, applications) may have a huge impact, when assessing the feasibility of hardware and software solutions. Moreover, it is challenging to design a mobile ad-hoc network so that it would provide good performance over all communication technologies (Takai et al, 2001), because most of these communication technologies behave differently in terms of wireless range, data rate, etc. Table 1 compares the 5 most important existing wireless communication technologies.

The above was an explanation of the technologies that exist as of this moment. One key component that these environments lack is the ability to communicate locally as is no networking infrastructure available (e.g. in a constructing site). This requires these devices to message (protocol) with each other and set communication paths automatically. These paths are not only enabling communications with an immediate worker, but also other parties located in the site. This behaviour is enabled through the use of an ad hoc networking protocol, such as

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[1] HIPERLAN - HIgh PErformance Radio LAN

[2] ETSI - European Telecommunication Standards Institute

[3] BRAN - Broadband Radio Access Networks

AODV. The following sections explain about these protocols and AODV in particular with some test results done on 2 AODV implementations, one of which was developed at ComNets, University of Bremen.

3. MOBILE AD-HOC PROTOCOLS

3.1 Overview of mobile ad-hoc protocols

The suit of computer networking protocols defined at the Internet Engineering Task Force (IETF) referred to as IP is the primary networking protocol that is used throughout the world to connect computing devices. The widely used protocols of this suit are in use for a number of years and are not appropriate for an environment described above, due to the temporary nature of the network links and the additional constraints on devices (limited bandwidth and power). This means, underlying (?) routing protocols must be able to keep up with the high degree of device mobility that often changes the network topology drastically and unpredictably. A mobile ad-hoc networking (MANET) working group has been formed within the IETF to develop a routing framework for IP based protocols in such an environment. These protocols are referred as mobile ad-hoc networking protocols (Perkins, 2000).

Due to the limited transmission range of wireless interfaces (WLAN, Bluetooth, etc), multiple hops may be needed in this environment. As devices in the network can move freely and randomly, frequent topology changes occur and this routing protocol has to be able to handle such changes efficiently. The proposed mobile ad-hoc networking protocols fall into two categories (Perkins, 2000).

- Reactive (Source-initiated on-demand driven)
- Proactive (Table-driven)

Reactive or source-initiated on-demand driven routing protocols do not maintain permanent routing tables. Routes are discovered only when originating device needs to send data. The originator initiates the route discovery procedure. When the route is found, it is being maintained as long as it is used to send data. The disadvantage of this approach is the start up latency that route discovery might produce. But, in small networks this is usually not the problem, but in networks with a great number of nodes it can be a limitation, especially for real-time traffic.

Proactive or table-driven routing protocols maintain the routing information from each device to every other device in the ad-hoc network, regardless of whether the route is ever used. To store all the necessary information, one or more tables are being maintained by each device. If a change in the network topology occurs, the updates about the change are propagated throughout the network. The disadvantage of this approach is the inefficient use of bandwidth, which is a scarce resource in ad-hoc networks. Further, the excessive control traffic consumes the power, which is also the problem with battery driven devices. On the other hand, since the route to each destination is always available, there will be no delays in traffic handling which is necessary for real-time traffic.

There is no single ad-hoc routing protocol, which is the best in all situations. Depending on different scenarios (probability of topology change due to the mobility of devices, size of the network in terms of devices) and applications used, various protocols may have more or less advantages/disadvantages. A reactive protocol might be a good candidate to enable wireless connectivity between workers in an environment described above in order to reduce congestion of the network and to save battery life of devices. AODV (Ad-hoc On-demand Distance Vector routing) is one such protocol, which is widely established and is published as an experimental RFC (Perkins et al, 2003) at the moment.

3.2 Operations of AODV

This section explains the basic operations of the AODV routing protocol. Considering a simple example (Fig. 2), the device A needs to communicate with the device D. Since, at the moment the device A does not have any link (called a route) to D and also no knowledge of where D is, it starts by sending a request asking where D is located. This is called a Route Request (RREQ) and this RREQ is multicasted (Perkins & Royer, 1999), i.e. it is generated to be heard by all the devices in the immediate vicinity. Immediate vicinity is the area where A’s signals are able to be received. This is also called the first hop. This request will be received by devices B and E. Since B and E are not aware of a link to D, they simply propagate this RREQ to their neighbouring devices. These are F and C. Since B and E might have to send the response of D, called the Route Reply (RREP) back to A, both of these devices keep a link (route) back to D. This is called the Reverse Path. Once the RREQ is received at the device D, it responds with a RREP (Fig. 3). This RREP, when heard by C, using the Reverse Path that was kept, it propagates this RREP, to B. B in turn does the same, sending this RREP to A, who was the original requester. When the RREP is heard by all the devices on the path to A, they keep a link to D, before propagating the RREP. This is called the Forward Path. Once the link is established between A and D, the data that was required to be sent from A to D goes through the devices B and C. In this example, B and C act as a router to the communications between A and D.

A can send RREP-ACK to D upon receiving the RREP in order to make sure of the bi-directional path. At the beginning of the RREQ process, the devices E and F also propagate the RREQ, thinking that D can be somewhere in that path. But since an RREP was not received by E or F, they simply discard the Reverse Path that they have set.

The links of the ad-hoc network are dynamic and are based on the proximity of one device to another device and their wireless coverage. These links are likely to break and change as the devices move across the network. For example, if C moves to somewhere else, then the link from A to D breaks. When this happens, B, the only device left in the link, informs A by sending a Route Error (RERR) of the breakage of the link with D. And since, there are no devices between C and D, D itself realizes that the link with A has broken. When A receives the RERR, it discards the original link information and restarts the RREQ-RREP (route discovery) process to find D again.

Since devices periodically send RREQs until they receive a RREP, the AODV protocol defines two numerical entities in the RREQ. These are called the sequence number (SEQ) and the broadcast identification number (ID). The ID is used to prevent the devices from processing the same RREQ more than once. The SEQ is used to identify the most recent route applicable to a device. The higher the SEQ, the more recent it is. This will ensure that the devices in an ad-hoc network will hold only the latest of the routes and will discard any information related to older routes.

Once a route is established on a device, it can reply to other RREQs, which request for the same destination device rather than propagating it to the destination. For example, if E needs to find a path to D, first its RREQ is picked by A and then, A replies to E that it has a route to D and E forwards packets to be sent to D, to A.

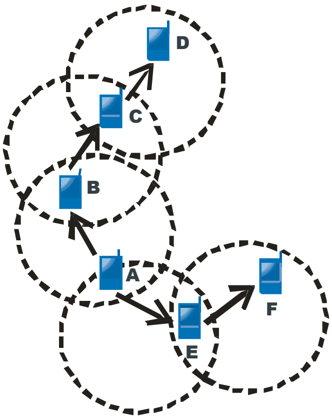

FIG. 2: Finding a routing path

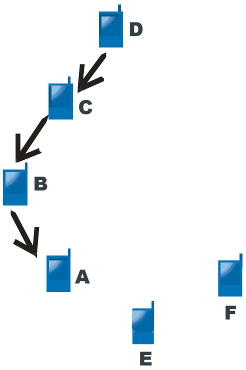

FIG. 3: Establishing a routing path

Each device which has active routes, starts multicasting a special RREP message, called HELLO messages. The link layer connectivity to the immediate neighbours can be detected using the link layer information or listening to HELLO messages. When a device detects the link failure, a route error (RERR) is sent back via separately maintained precursor lists to all originators that are affected by failed link. When the originator receives the RERR, it can start a new route discovery process again. Unused routes in the routing table are expired using a timer-based technique.

AODV uses the UDP protocol to perform all the above explained controlling signals. AODV works in identical ways in both IPv4 and IPv6.

4. IMPLEMENTATION AND DEPLOYMENT ISSUES

This section addresses some issues related to implementation and deployment of the AODV networking protocol. AODV has been deployed on a small scale in controlled environments in various laboratories around the world.

4.1 Implementation issues

Being a network layer implementation, the AODV protocol requires the following capabilities to be present in the programming language to develop an AODV protocol handler (Kuladinithi, 2003).

- **Unicast and Broadcast Communications**: The AODV controlling messages are UDP and should be destined to port 654 of the recipient. The RREQ and the RERR that are sent to be heard by all the devices in the vicinity are broadcasted. The other 2 messages of AODV, the RREP and RREP-ACK require unicast communication.
- **Listen to IP Traffic on a Given Network Interface**: The protocol handler requires listening to IP traffic on the AODV capable network interface for the following reasons. I.e., to initiate the route discovery process when the originating device requires to communicate with another device in the AODV network and to obtain the activity level of each of the currently available routes (which were created due to requirement of the originating device or other devices in the AODV network)
- **Manipulation of the Routing Table**: The AODV protocol requires that the routing table be set according to the requirements of the other devices in the AODV network. This requires the protocol to instruct the operating system to set and remove routing entries.
- **Supporting a Timer Mechanism**: The AODV protocol requires that a set of timers is made active to manage the different lifetimes of different processes. Some of these timers perform different tasks after they reach a certain time and expire themselves. Others continue to be active as long as the protocol handler is active. For example, to manage the route discovery process, by sending RREQs until a route is made to a destination or a destination is not reachable, to manage the expiration of IDs used by each of the RREQs generated in route discovery processes, to manage the sending of HELLO messages to the immediate neighbours, etc.

As of this article, there are several implementations of the AODV protocol that operates on different operating systems (e.g., Unix/Linux, Windows), different devices (e.g. Notebook computers, PDAs) and which have been developed using programming languages such as C, Java, etc. An interoperability test, a test that measures the level of interoperability of some of these implementations, was done in 2002 (Belding-Royer, 2002). Several simulation results have proved that AODV networks can be scalable up to 1,000 nodes without any performance degradation (Lee et al, 2003).

TCP and UDP applications have been evaluated based on two different AODV implementations by the authors. Following section shows a summary of those results and more information can be found at (UoB-JAdhoc, 2003).

TCP and UDP performance over an AODV Network: These tests were carried out using 6 notebooks of having Mobile AMD Duron processors at 1.1 GHz and 256 MB of RAM. For wireless connectivity, Cisco Aironet IEEE 802.11b wireless cards were used.

Test Scenarios: Both JAdhoc, an implementation by ComNets, at the University of Bremen, Germany (UoB-JAdhoc, 2003) and AODV-UU, an implementation by the Upsala University, Sweden (AODV-UU, 2002) were installed to provide AODV functionality. The performance evaluation was based on UDP and TCP flows which are generated by the iperf traffic generator (Tirumala, 2004), varying the generation rates. The test-bed is configured to work in 3 test modes.

- **Static Mode** : Routing environment of all nodes is set manually as if they are in an AODV network.
- **UU Mode** : Each node sets routes on demand using AODV-UU protocol handler.
- **JAdhoc Mode**: Each node sets routes on demand using JAdhoc protocol handler.

UDP test: Maximum data rate of UDP stream that can be transmitted without any packet loss was measured, when test-bed was in static mode. It was found that a data rate of 3.6 Mbps can be transmitted between two nodes without any packet loss. Since the same frequency channel is used for all 6 nodes for the above test, it can be assumed that 3.6 Mbps divided by 6 to be the maximum UDP data rate that can be transmitted between 6 nodes without any packet loss. Therefore, UDP data rates of 512000 bps was chosen to measure the key attributes of a UDP communication of packet delivery ratio, actual load, jitter and analysis of out of sequence packets. Following measurements were taken for both UU and JAdhoc, when varying the number of nodes from 2 to 6.

TCP test: At first, TCP throughput was measured by varying the nodes from 2 to 6, when test-bed was in static mode. It was found that there were considerable numbers of TCP retransmissions generated that affects the throughput (lower), with the increase of nodes. This is due to the packet loss, because of the collision in the air when using one frequency channel.

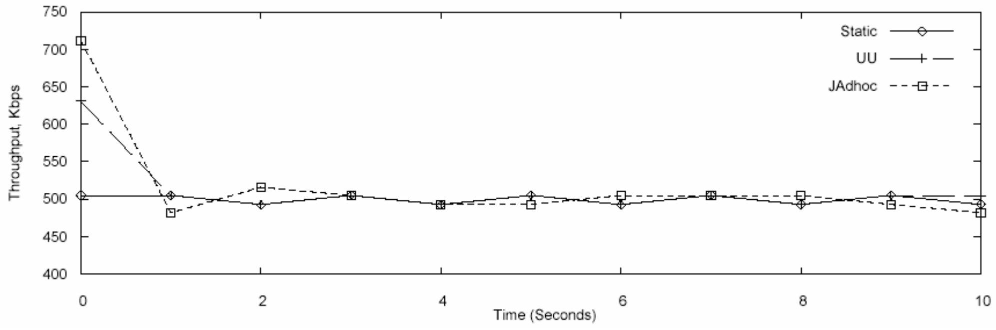

FIG. 4: UDP throughput variations (between 4 nodes) at the receiver

Compared to the static mode, both UU and JAdhoc have higher throughput than the given throughput of 500 kbps during the first second. At the beginning, AODV protocol handler buffers the packets and starts the route discovery process and it releases all buffered packets at once, causing higher throughput. There is a packet loss during this time due to the fact that the offered load can not be handled at the link layer. However, the measured packet loss for 6 nodes lies around 1 to 1.5 % for both AODV implementations. UDP based communications can be used for video conferencing between workers. Measured values of packet loss rate of 1-1.5 % (mostly at the beginning of communications) and the average jitter of 2ms shows that UDP based video conferencing is feasible in AODV based networks.

The maximum TCP throughput between 2 nodes was measured at around 3 Mbps for both AODV implementations. These data rates are fairly enough to run applications such as FTP downloads (e.g. downloading images such as plans, blueprints) and any other TCP based web enabled applications (e.g. Finding locations, updating centralise databases such as stocks).

4.2 Deployment issues

AODV networks in the AEC industry can be deployed to enable the communication without the required intervention of a centralised access points or networking infrastructure. Since AODV is a network layer solution, any existing applications such as video conferencing, mail programs, graphic drawings, etc. can be run on workers' devices without any modifications and also these applications can be secured with existing security mechanisms such as SSL, SSH or IPSEC.

AODV routing protocols have been simulated for different environments, while varying size of number of devices (nodes) and their topologies. These simulation results show that AODV can function in an environment of 10,000 nodes with a net diameter of 35 nodes (i.e., the maximum hops between originating and destination nodes can go up to 35 hops). Acceptable performance has been shown for AODV networks with up to 1000 nodes (Das et al., 2000) in a simulated environment.

In general, a practical AODV environment consists of mobile devices of limited bandwidth (hundreds kbit/s to few Mbit/s), battery driven and with the transmission capability of up to a limited range (up to 100m). The AODV routing protocol is still not widely deployed commercially. Considering the deployment of AODV networks in a practical environment, the following issues have to be addressed.

Scalability: size of a network in terms of number of devices. With current wireless technologies such as WLAN 802.11b, scalability problems surfaced, with the increase of number of devices, due to increase of packet loss in the air with the increase of devices sharing the same wireless channel. And also, at higher device populations, when hop counts increase, users can experience increased latency and broken routes. There are few theoretical studies, which tried to estimate per device capacity and throughput that can be expected in ad-hoc networks. In [Gupta, 1998], it is concluded that end-to-end throughput available to each device in the network with N devices under optimal conditions is 1/sqrt(N). That is, if the number of devices in the network grows to infinity, available throughput per device becomes zero.

Power consumption: how long can a device function? This refers directly to the battery life of a device that finally decides the lifetime of the whole AODV network Efficient power consumption of mobile/wearable devices relies on the design of more specialized and efficient (faster, smaller, less power consuming) hardware that suits the mobile computing environment. Perhaps, these devices can be designed to use other means of energy such as solar power.

Quick convergence: if a worker moves, is it still possible to communicate with other devices? In real AODV networks, movement of workers that are engaged actively (i.e. acts as routers to other devices) will affect the reliability of an AODV network. Even though one worker moves out of the coverage area, communication can be recovered as far as another workers' device can provide the path. In an environment such as workers' movements can't be predictable, a fixed flexible device/s can be installed in order to make sure that workers can find the route to each other at anytime.

4.2.1 Ongoing research

At the moment, AODV is considered as a protocol which continues to show promising results in the realm of research. There are several on-going research projects to improve the efficiency and performance of the AODV routing protocol. Some of them are listed here.

Location based routing: In order to limit flooding of the network, the estimated location information, based on the last known position, direction and speed is being used to limit the area which is flooded with control messages. Also, the criterion for choosing the best next hop in the route to destination, based on location information, is proposed (Schwingenschlögl et al., 2002). This approach is suitable for an AODV network that can be deployed outdoors where devices can receive location information (e.g. GPS).

Multi-path routing: AODV networks as proposed in the base specification, always find the shortest path between the source and the destination devices. There are several proposed solutions for AODV to utilise more than one routing path in order to keep others as a back-up path and also to use these paths for the purpose of balancing the load (Marina et al, 2001 and Kuladinithi et al, 2003).

Route discovery based on QoS parameters: During the route discovery process, Quality of Service (QoS) constraints (available bandwidth, delay parameters) are considered and proposals attempt to find a best path based on the predefined QoS parameters (Perkins et al, 2003).

Connecting to Internet: In addition to communicating within the AODV network, these workers also require to have access to the Internet. Access to the Internet can be obtained through a device that can act as a gateway to the Internet, while operating in an AODV network. The other devices can access the Internet via this gateway (Jonsson et al, 2002).

5. CONCLUSION

Wearable computing is a new paradigm in the use of computing. These computing devices which have almost the same capabilities as other personal computing devices can be used to improve the effectiveness and the efficiency of field based workers. Access to information related to the activities that workers have to perform at the correct time and at the correct place, brings about these improvements. The nature of field based working environments or similarly characterised environments, is that the users (workers) operate in situations that have no proper communicating infrastructure and that these users need to be mobile. Ad-hoc networking allows mobile workers with mobile communication devices to set up, possibly, a short-lived network just for the communication needs of the moment, without the required intervention of a centralised access points or existing networking infrastructure.

This article described one such networking protocol called AODV. This protocol offers quick adaptation to mobile networks with low processing and low bandwidth utilisation and determines the path between source and destination devices on demand. The AODV protocol allows the workers to create networks on the fly between the computing devices of other workers in the physical environment and also to obtain access to the Internet. AODV has been implemented in a few operating systems and has undergone interoperability tests between these implementations. AODV is still in the realm of research, but with promising results for its adaptation in commercial environments. The final section of this article looks at some issues related to both implementation and deployment of AODV in a commercial environment.

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