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Internet of Things for Measuring Human Activities in Ambient Assisted Living and e-Health

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Abstract

Internet of things (IoT) is a new paradigm that combines several technologies such as computers, Internet, sensor networks, radio frequency identification (RFID), communication technology and embedded systems to form a system that links the real world with digital world. Currently, a large number of smart objects and different type of devices are interconnected and more and more they are being used in Ambient Assisted Living (AAL) scenarios for improving the daily tasks of elderly and disabled people. This paper presents an IoT architecture and protocol for Ambient Assisted Living and e-health. It is designed for heterogeneous AAL and e-health scenarios where an IoT network is the most suitable option to interconnect all elements. Finally, we simulate a medium-size network with four protocols especially designed for networks with important energy constraints in order to show their performance.

Keywords: Internet of Things (IoT), People-centric, Ambient Assisted Living (AAL), E-health, Routing Protocols, Network Performance.

1. Introduction

Internet of Things (IoT) allow physical objects to be connected to Internet and allow them to self-identify and identify other devices. Initially, IoT was considered as a simple extension of the identification by radio frequency (RFID). But considering the evolution and the number of applications attached to the interconnection of objects, IoT has evolved from just some objects connected to Internet to objects that learn to anticipate their responses and understand their environment to adapt and enhance their actions [1]. IoT technology establishes a connection between all things and the Internet. It is widely applied in intelligent transportation, environmental protection and animal monitoring [2], intelligent buildings, public safety, positioning, tracking, and monitoring and smart management.

One of the sectors that most can benefit by the use of and IoT infrastructure is Ambient Assisted Living (AAL) and e-health. When implementing an AAL, several features should be considered. Sensors should be non-invasive systems and should be able to wirelessly communicate with the rest of devices of the data network. Moreover, AAL systems should be able to act when they detect any abnormal situation without the explicit request of a user. AAL systems should be able to adapt by their-self when abnormal situations happen. AAL must ensure the persons' welfare, i.e. monitoring illnesses, controlling the provisions of fresh food, enabling people-to-people communications [3], etc. Recent advances in household appliance monitoring are allowing them [4].

Because of the interest of joining IoT with AAL and e-health applications, in this paper we present the most important parts to take into account for implementing IoT networks and compare the most common architectures that, despite not being standards, are widely used. We also include a description of the main protocols used in IoT in order to propose a heterogeneous IoT scenario composed by several networks focused on e-health, AAL and people monitoring. Finally, we evaluate the network performance as a function of the used routing protocol.

The rest of this paper is organized as follows. Section 2 shows some previous works related to IoT and AAL proposals based on IoT. Common IoT architecture models and stack protocols that are currently using are explained in Section 3. Section 4 shows some of the most important e-health and AAL applications and services that can be improve using IoT. Section 5 proposes a scenario that includes the needed e-health services for monitoring people activity and some simulations to evaluate the protocols working in this kind of networks. Finally, Section 6 draws the conclusion and future works.

2. Related Work

E-health and AAL are people-centric systems where the technology is highly beneficial to elderly and disabled people. This section shows some of the most interesting papers regarding to the issues to be considered for implementing an IoT solution and the use of IoT for people monitoring, where sensors placed over the people (patients, in most cases) help doctors and caregivers to understand each person as a source of information inside the data network.

There are several previous works that covers different aspects of IoT technology. P. Lopez et al. [5] provided an overview of IoT for mHealth and eHealth applications. This work analyzes the technologies 6LoWPAN/IEEE 802.15.4, Bluetooth Low Energy (BT-LE), and Near Field Communication (NFC) for personal clinical devices and defines when each technology is more suitable. Y. Huang et al. [6] presented a novel bicycle parking system based on IoT. It is composed by a bicycle carport subsystem, a controlling and information subsystem, and an alarm subsystem which can record and process all information of parking sites as well as the information of bicycles parking in the carport. It was developed to make easier the management of bicycles and to reduce the bicycle thefts.

An IoT system developed for monitoring people activity was presented by W. Qiuping et al in [7]. They proposed the use of IoT for mine production monitoring. They used wireless technologies and sensors to prevent and reduce accidents in the mining sector due to water flooding, fire, gas and coal dust and of roof collapses which make this activity one of the most dangerous jobs in the world.

AAL systems are being developed for enhancing the quality of life and welfare of elderly and disabled people. Several aspects should be considered in AAL systems, e.g. the system architectures, design and development methodologies, systems and services, technology standards and security, privacy and data protection issues, among others [8]. There are several studies that explain how sensors and actuators, using IoT technology can be integrated in AAL systems [9]. Following this idea, R. Blasco et al. [10] present the design, implementation and assessment of a Smart Kitchen which improves the elderly and disabled people's autonomy in their kitchen-related tasks. The system is composed by a physical architecture which integrates systems such as household appliances, sensors or user interfaces and software based on the Open Services Gateway initiative (OSGi).

L. Meinel et al. [11] presented a real-time video surveillance system based on an omni-directional camera and a system for multiple objects tracking for AAL applications. The system is able to track multiple persons entering and leaving the room. The real-time video surveillance system can monitor the entire room with a single camera. During the person registration, the system creates a virtual perspective using signal-processing techniques. Finally, the software is implemented in an embedded platform, which acts as a smart sensor to capture the people presence.

Finally, J. Lloret et al [12] presented a communication architecture for AAL which uses data gathered from the sensors, the unexpected persons movement, traffic patterns and network frames to intelligently make decisions over strange situations of a elderly or disabled person. The system included artificial intelligent systems in order to provide the most appropriate actions for the proposed AAL architecture.

As far as we know, none of the aforementioned papers have considered the people as an element of the data network which can provide information from two points of view. The first one is the wearable sensors that a patient can wear to monitor their vital signs. The second one is the possibility of people interaction with the network and actuators controlled by the

IoT infrastructure. The integration of intelligent system that takes into account strange human behavior in order to intelligently decide about the most appropriate action is also a current challenge that very few proposals include. This study is motivated by the increasingly tendency of the society to equip our public institutions as hospitals with large number of wireless sensors and actuators. In most cases, researchers tend to use specially designed protocols for wearable devices disregarding the versatility and compatibility of communications of these devices, with the own data network already deployed in the building. Finally, the possibility of using common routing protocols in this kind of networks has not been considered and, for this reason, we want to test energy-efficient protocols in an IoT network used for people monitoring.

3. Architecture and protocols for IoT

IoT should be able of interconnecting thousands of heterogeneous devices through Internet. For this reason, it is needed to have a flexible architecture capable of working under multiple platforms. This section explains the common architecture model and IoT stack protocols [13].

3.1 IoT architectures

In order to better understand the operation of IoT, it is needed to divide the IoT system in several small blocks with well-defined tasks (See Fig. 1).

The first task in IoT services is to identify the object requesting a service. This task can be performed using several methods such as electronic product codes (EPC), ubiquitous codes (uCode) or RFID targets, among others, so they will be placed at this level. A sensing process is also needed in most cases. In this case, the system/device gathers data from de medium and/or network in order to better adapt its responses. The Processing unit included in the device processes the data and decides how to proceed according to the requested service and user needs. An intelligent algorithm can be applied at this level in order to enhance the system response. It can be applied thanks to the presence of the processing unit in each device which allows distributed processing. After making the correct decisions it is needed a layer for the communications between devices through the network. This can be done with different communication technologies such as WiFi, Bluetooth, IEEE 802.15.4, Near Field Communication (NFC), Zigbee or 3G or 4G mobile networks, among others. Obviously, linked to each communication technology, we should consider other elements such as routing and MAC protocols in order to integrate each device as an element of the network. Moreover, energy constrains are taken into account to enlarge the network lifetime as long as possible. Last layer considers the services where the system is implemented. The range of services offered in IoT is very broad. We develop an IoT architecture to e-health sector, precision agriculture, automotive sector, industry sector, etc.

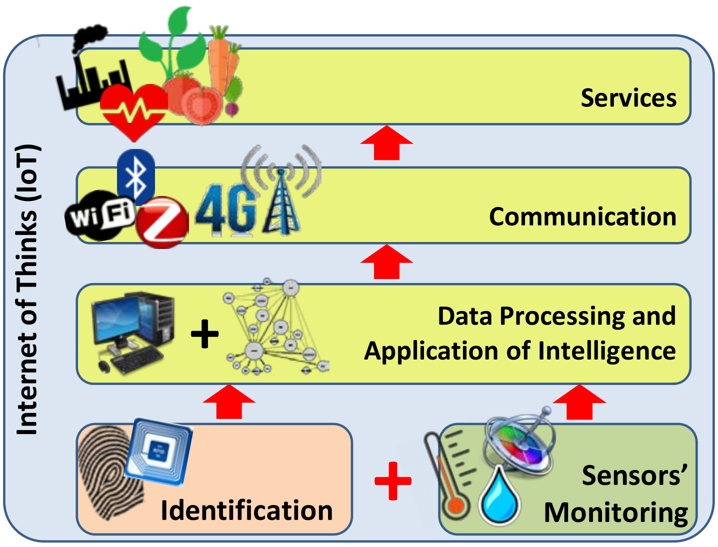


Figure 1. Elements in IoT

We can now focus our effort on understanding the common IoT architectures. Fig. 2 shows the two most common architectures. There have been big efforts from the research community because of the great increase of devices capable of being integrated into IoT architectures to define a reference model.

In industry and in scientific research fields, the IoT architecture can be divided into 3 layers as follows:

The Perception layer: This layer is focused on the identification of objects and collecting information from users, environment and requested services. It is composed by physical objects and detection devices such as RFID, bar code or distance sensors, etc. The selection of the appropriate detection device will be defined by the requested service. Some examples are location, temperature, direction, movement, vibration, acceleration, humidity, chemical/physical changes in the environment, etc. The collected data should be transmitted to the upper layer for transmission.

The network layer: Its main function is to process the data received from the perception layer and its safety transmission over long distances. The data can be transmitted wirelessly although wired and wireless networks are often combined. The network layer can include several communication networks with different technologies that give service to several applications and population sectors. The network layer is in charge of improving the exploitation of information on the network. It should be able to aggregate information from existing infrastructures such as health care systems, transportation systems, power systems, etc.

Application layer: This layer provides overall management of the application on the basis of the information processed in the network layer. It is the top layer and it is used to process intelligently the massive data and perform the data aggregation from various sources with diverse types. This layer also comprises the interactivity of the application/service/network with the user through tactile screen display. It also implements the control and management of objects' information by making use of cloud computing, data mining, middleware business management, and so on. The most common applications implemented in this layer are smart agriculture, smart home, smart city, smart transportation, etc. The way of implementing this layer is directly related to the application or implemented service. The most important issue is to share information between communities and ensure safety.

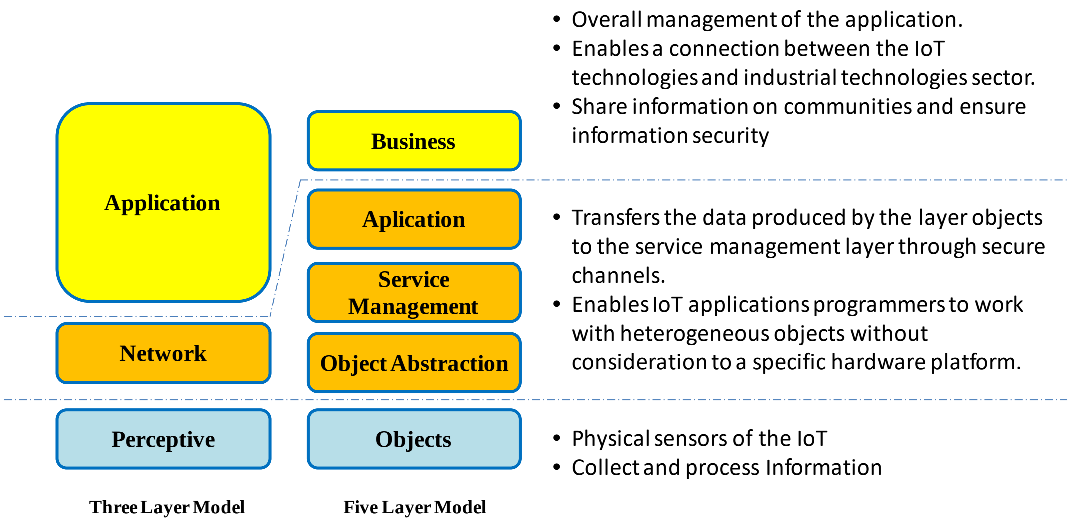


Figure 2. Comparison of IoT architectures

There is an alternative IoT model based on a 5-layer reference model. In general, both models implement the same functions but 5-layer reference model delimitates in major degree the associated task to each layer. As Fig. 2 shows, the perceptive layer in 3-layer model matches with the objects layer in the 5-layer model. On the other hand, the Business Layer in the 5-layer model matches with the application layer in 3-layer model. However, some of task performed by application layer in 3-layer model are not included in the business layer. The Network layer in 3-layer model is subdivided into 3 layers in the 5-layer model. The tasks performed by each one are the following:

- **Object Abstraction Layer:** This layer refers to the data produced by the layer objects to be sent to the service management layer through secure channels. Data can be transferred to the upper layer using several technologies such as RFID, 3G, UMTS, WiFi, Bluetooth Low Energy, infrared, ZigBee, etc. It is also interesting to cite that this layer can process data provided by the cloud to enhance the system response.
- **Service Management Layer:** It enables IoT application programmers to work with several devices independently to the used hardware platforms. In addition, this layer is in charge of taking decisions to provide the best response as a function of the requested service.
- **Application Layer:** This layer provides the services requested by customers. The important role of this layer is that it has the ability to provide high quality intelligent services to meet customer needs. It covers several markets such as smart home, smart building, transportation and health, among others.

Because there is no clear reference model, researchers try to find similar models in other architectures. However, the architectures where layers depend on the upper and lower layers (especially in the three-layer model) do not match with the actual needs of IoT environments. To cite some examples, the Network layer does not cover all technologies that transfer data between several IoT platforms. This is because these reference models are specifically designed to work with other kind of networks such as sensor networks. This kind of reference models considers devices with some limitations, such as energy constrains or low processing capacity. On the other hand, in the 5-layer model, the application layer is the interface through which end users can interact with a device to obtain the data. It is also the interface to the business layer. The tasks performed by this layer are hosted on powerful devices because of their complexity and big computing requirements. Taking into account these aspects, 5-layer architecture could be more suitable to develop IoT applications and to understand their different tasks and functions.

3.2 IoT Protocols

The key problem with IoT standardization is the limitations of the environment of IoT characterized by low storage capacity, energy constrains, low available bandwidth and high packet loss because IoT does not allow TCP/IP protocol to reduce these losses. Fig. 3 shows a comparison between the IoT stack protocol and Web stack protocol.

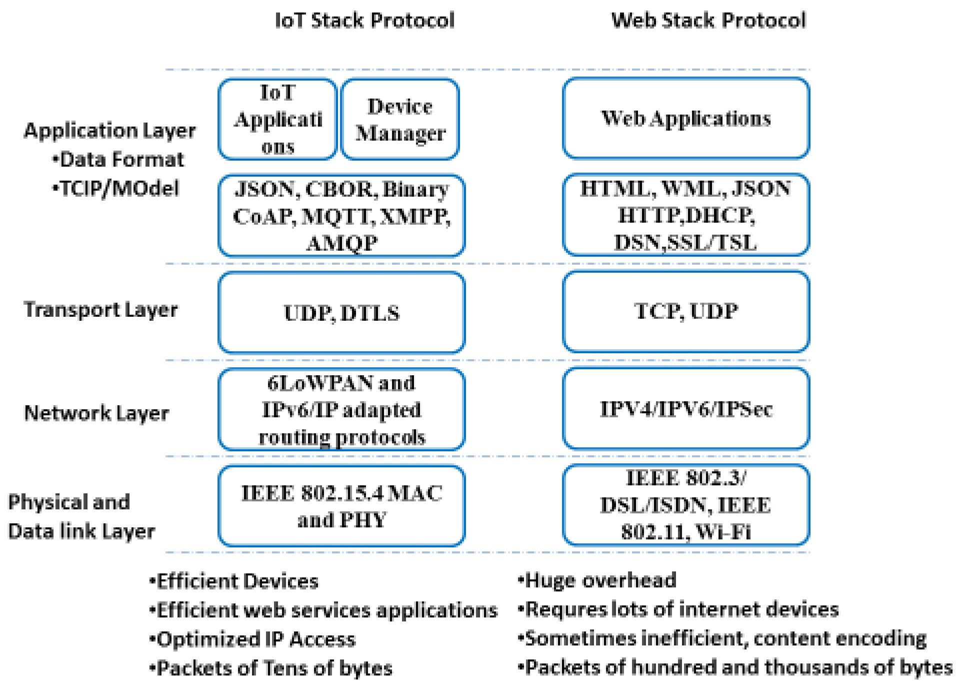


Figure 3. IoT Stack Protocol vs. Web Stack Protocol

To solve this challenge, there are hundreds of proprietary protocols in IoT, M2M (Machine to Machine) and home automation environments such as ZigBee and BLE (Bluetooth Low Energy) or Bluetooth 4.0. These protocols are supported by an alliance of product vendors. However, they are not standardized like TCP, IP, HTTP or SMTP. As aforementioned, IoT scenario is still a bit confused. Most international standardization associations such as IEEE, IETF or W3C have standardized protocols such as 6LowPAN (IPv6 over Low power Wireless Personal Area Networks) or CoAP (Constrained Application Protocol) and it is believed that other IoT protocols will be standardized like the web standards used today. There are several application layer protocols that can be used for IoT. The future of IoT lies in standardizing the protocols used across network stack. These set of open and standard protocols like CoAP, MQTT (MQ Telemetry Transport) and 6LowPAN would eventually become as successful as the TCP/IP stack used across the web and Internet.

4. IoT for E-Health

IoT can change the lifestyle of humans. Recently there have been a number of independent researchers that investigated the potential of integrating concepts of the IoT in human life [14]. IoT can provide several benefits to improve the quality of life for citizens and prove lifestyle suggestions for welfare. This section explains some of the most important applications and services that IoT can improve in e-health field.

- **Health care**: The rising costs of health care and the increasing availability of new personal health devices are the ingredients of the vision of IoT in the connected healthcare. The vision of connected healthcare is growing because of the availability of new technological tools. IoT and new technologies can be used to create a health app to collect data from the patient automatically. IoT can help doctors to respond quickly in emergency situations and allow them to cooperate with international hospitals to track the status of a patient. IoT applications can be found also in home monitoring especially for elderly people with special needs or chronic illnesses such as diabetes and congestive heart failure. There are also other applications of IoT such as patient identification. This application aims to reduce adverse events for patients and maintenance of comprehensive electronic medical records. IoT based on RFID tags in the medical domain enable rapid and accurate identification of every intelligent entity, enabling a universal and fast access to personal health records.
- **People with disabilities and special needs:** IoT can be applied to many cases. Next we can find some examples. People who are hearing impaired can benefit from external or internal devices (implanted in the ear) to improve hearing. A wireless low cost glove designed to help a deaf to communicate with those who are not familiar (it can recognize hand signals and convert them into voice interface with a Java-enabled monitoring station). The blind navigation system can help them to find their way into a store (a RFID system can use software to guide the visually impaired in shopping). IoT is also used to monitor and control various components in cars. Ford and Intel have teamed up in 2014 to explore new possibilities to customize the user experience by using facial recognition software in mobile phones.

5. AAL People-Centric Monitoring system based on the IoT paradigm

The importance of AAL for elderly and disabled people is increasing day by day. This is because the improvements in the medicine field are generating changes in the lifestyle of developed countries and this fact is increasing the life expectancy in the population. According to the European Commission, by 2025 more than 20% of Europeans will be 65 or over, with a particularly rapid increase in the number of over 80s. Thus, this section proposes a scenario that includes the needed e-health services to monitor people activity and help caregivers to be in alert for possible emergency situations. We explain the elements that, according to the previous sections, are involved. Finally, we simulate the network performance using four common routing protocols especially designed to enhance the energy problems in wireless devices.

5.1 AAL and e-Health structure for people monitoring from everywhere

In order to implement an AAL and e-health service network that allows human activity monitoring, we must take into account several aspects. Our proposal includes a set of small networks that implement specific services, such as patient monitoring in a hospital setting, management of the emergency services or remote monitoring of elderly and disabled people from their homes, etc.

This means that we need to differentiate between three specific layers (see Fig. 4). Lower layer considers the integrated services of this network. In this layer, we find the sensors that allow real-time people and vehicles monitoring (i.e., position or vital signs) and actuators that can run very concrete actions taking into account the signals received from the sensors. The second layer will be responsible of grouping the sensors/actuators and integrate them into the network. Finally, the top layer offers the interoperability and interconnectivity to all different services. This layer takes into account all possible communication techniques and elements of a data network such as mobile networks, Wi-Fi networks, and cloud computing services, among others in order to allow the communication between grouped networks.

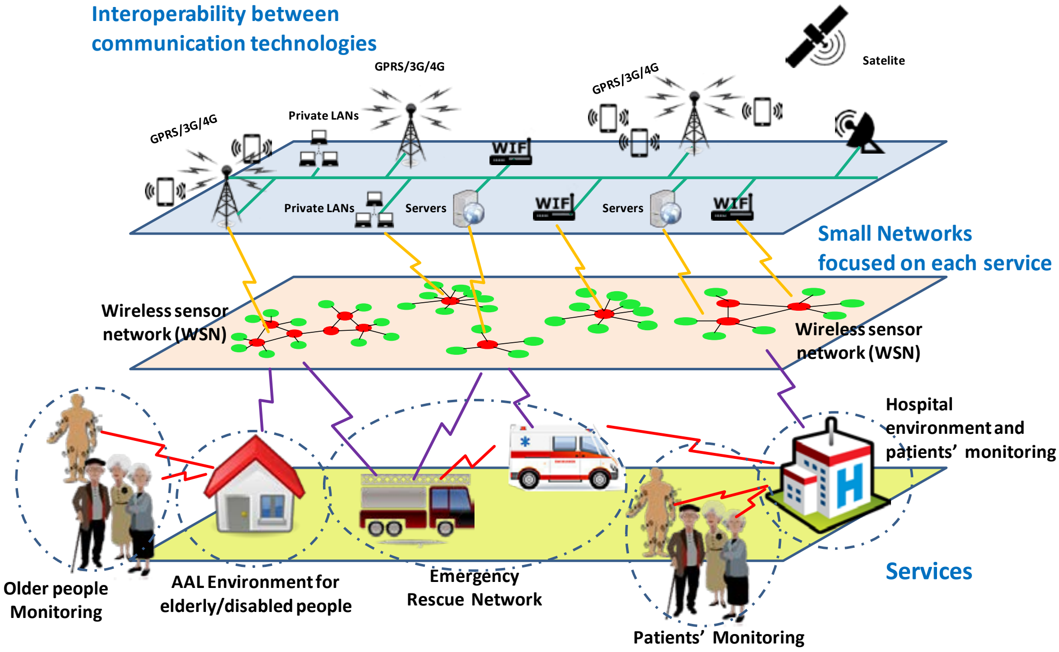


Figure 4. AAL heterogeneous Scenario based on IoT

5.2 System Simulation

There are many constraints to simulate a network with these characteristics. However, we can analyze parts of the network. In order to evaluate an IoT infrastructure in an AAL environment, in this section, we have simulated a medium size network that could be deployed in a house scenario or small hospital.

Routing protocol is responsible of forwarding packets and make intelligent routing decisions. RPL (Routing Protocol for Low power and lossy networks) is the standard routing protocol for environments such as 6LoWPAN networks and IoT. We have performed a first simulation in a small-size network using Contiki Cooja simulator (See Fig. 5a). We designed a network composed by 20 client nodes and one server node. To perform this simulation, we used ETX (Expected Transmission Count) and OF0 (Objective Function Zero) to help us to rank computation level. The objective of this experiment is to evaluate both functions in terms of energy consumption. The results show that RPL is a very powerful technique. However, the clear tendency is to use common routing protocols used in WSNs by applying them to an IoT scenario. To perform the rest of simulations we have used the following protocols:

- **Low Energy Adaptive Clustering Hierarchy (LEACH):** It is a clustering based hierarchical protocol in which most nodes transmit to cluster heads, and the cluster heads aggregate and compresses the data to forward it to the sink, commonly known as base station. LEACH considers that each node has a radio transmission power enough to directly reach the base station or the nearest cluster head. LEACH is able to increase the network lifetime.
- **Threshold sensitive Energy Efficient sensor Network (TEEN)**: Sensor nodes continuously detect the environment but data transmission is only carried out when a parameter reaches a threshold value. The sensed value is stored in an internal variable in the node, called the sensed value. The protocol is based on the statement that the process of data gathering consumes less power than the transmission process.
- **Stable Election Protocol (SEP):** It assumes that each node has different energy. They are classified in levels and treated differently based on their initial energy levels. The nodes with lower energy are called normal nodes and assigned a weighted election probability which is lower to which id the weighted election probability assigned to the advanced nodes, i.e., the nodes with higher energy levels. This ensures that nodes with higher energy will have higher probability of being elected as CH. In this way, the network will consume the energy in a balanced manner which implies to prolong the network life time.
- **Energy-Aware Multi-hop, Multi-path Hierarchy (EAMMH):** The communication process in EAMMH protocol is divided into rounds. In the setup phase, the neighbor discovery takes place. After that, each node decides whether or not to become a cluster-head for the current round. During Data Transmission phase, sensor nodes are allotted timeslots to send the data. When a node receives data from one of its neighbors, it aggregates it with its own data. While forwarding the aggregated data, it has to choose an optimal path from its routing table entries. If no node in the routing table has energy level greater than threshold energy, it picks the node with highest minimum energy. The last

operation in EAMMH protocol is to send the updated about the paths and routing table entries at each node.

All of them are cluster-based hierarchical protocols especially designed to improve the network lifetime. To evaluate the network performance when working these protocols, we have defined the following parameters which are the most significant in cluster-based protocols.

Stability Period: Time interval from the start of the network operation until the death of the first sensor node.

Number of cluster heads per round: It shows the number of nodes sending directly to the sink information aggregated from their cluster members.

Number of death nodes per round: It shows the total number of nodes that have already consumed all their energy.

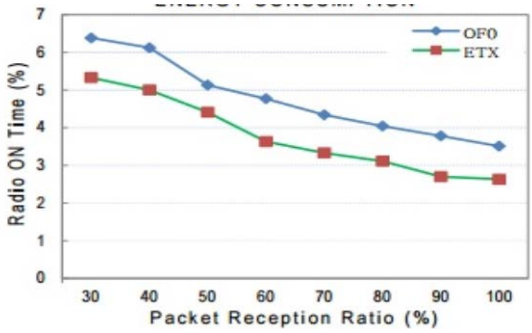
Throughput: Total rate of data sent over the network, (rate of data sent from cluster heads to the sink and rate of data sent from the nodes to their CHs)

Table 1 shows the simulation parameters used during the simulations.

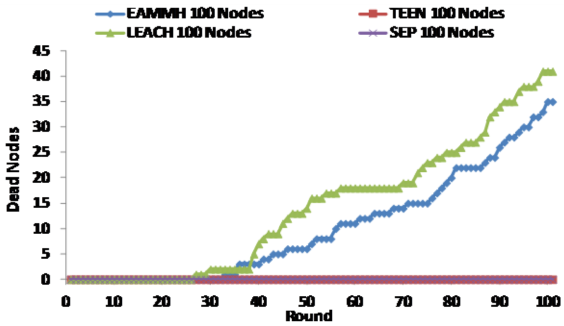
Table 1: Simulation parameters

Parameter	**Value**
Area size	100*m*×100*m*
Node placement	Random
Node numbers	100
Initial energy	0.1 J
Probability of a node to become cluster head	0.2
Percentage of nodes than are advanced	0.5
Transmission power consumption	50nJ/bit
Receiving power consumption	50nJ/bit
Data aggregation Energy	5nJ/bit
Eelec	50 nJ/bit
Eamp	0.0013*pJ/bit/m*2
Efs	0.0013*pJ/bit/m*2

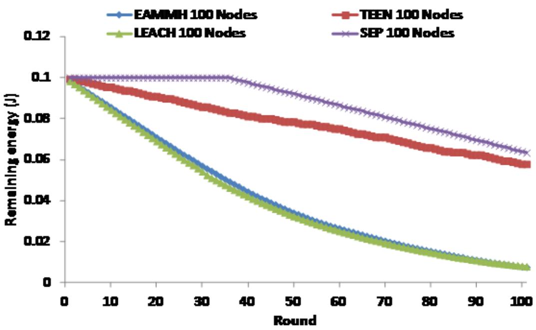
Finally, Fig. 5 (b to f) shows the protocols' performance in terms of average value of remaining energy in each node, Network lifetime, and the throughput which quantify the amount of packets the network need to properly work. We can highlight several aspects. The first one is that SEP is the protocol which presents the lowest energy consumption while LEACH and EAMMH present the biggest energy consumption (Fig. 5-c). LEACH and EAMMH also present the biggest rate of death nodes while TEEN and SEP do not register the drop of any node (Fig5-b). SEP is the protocol that consumes higher bandwidth because it sends bigger number of packets from nodes to the cluster heads (Fig. 5-d and Fig. 5-e). Finally, the number of packets sent to the Base Station per round (Fig. 5-d) and Number Cluster Heads per Round (Fig. 5-f) are similar for all cases.



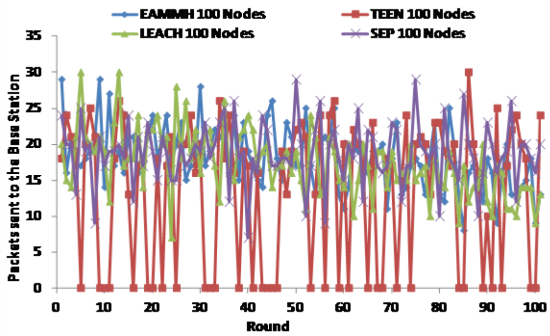
a) OF0 and ETX evaluation



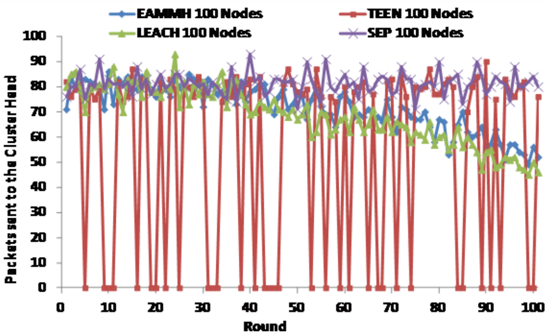
b) Dead Nodes per round



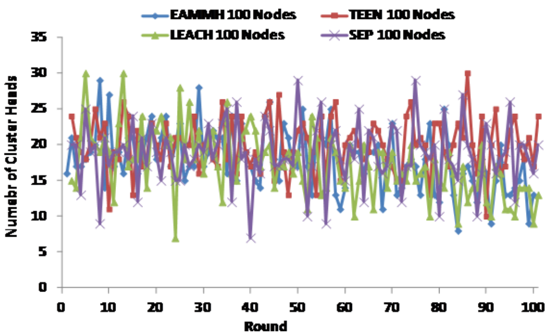
c) Average value of remaining energy in each nodes per round



d) Number of packets sent to the Base Station per round



e) Number of packets sent to the Cluster Heads per round



f) Number Cluster Heads per Round

Figure 5. Protocols evaluation

6. Conclusion and Future Directions

This paper has shown the architecture design and stack protocols to implement IoT networks. The paper also presents a common scenario which includes the main services required for AAL and e-health. Finally, we have simulated a medium-size wireless network with 4 different routing protocols specially designed to work with networks where the energy consumption can be a problem. The results show that TEEN and SEP could be suitable to work in a IoT network since they present the lowest energy consumption and does not register dropped nodes at the time that presents a packet volume similar to LEACH and EAMMH.

As future works, we will include more protocols (and some secure mechanism to avoid data vulnerabilities [15]) and we would like to implement it in a real scenario in order to compare the veracity of simulations than currently we can see in the related literature. We also want to check the network scalability with higher and lower number of wireless devices.

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