A comparative study of wireless communication protocols for monitoring vital signs in athletes in a soccer field

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Abstract: - This paper provides a comprehensive investigation of two wireless protocols performance over short range communications for monitoring vital signs in athletes, mainly during training. Live physiological monitoring of athletes during sports can help to optimize their performance at a specific time in order to maximize athlete efficiency and preventing undesirable events like injuries. ZigBee (over IEEE 802.15.4) is becoming a popular way to create wireless personal area network due to its low power consumption and scalability while Wi-Fi (over IEEE 802.11g) provides the solution for portability with connection of mobility as well. This article presents the evaluation results of system performance using OPNET simulation for the two different wireless standards. The evaluation is concentrated on providing results regarding network values such as end-to-end delay, traffic, average throughput captured from global and objects statistics.

Key-Words: - Wireless sensor networks, Performance evaluation, OPNET, Simulation, Throughput

1 Introduction

The evolution on sensors technology over the last decades has opened completely new fields for the modern technological applications. Nowadays, wireless sensors networks (WSNs) [1] constitute a promising field of research in the area of Wireless Communications, given the extensive breadth of applications that they can support. They represent a new order of operating calculating systems that extends the interaction between humans and the natural environment. While up to today the wired sensors networks were globally used, the growth of microelectronic systems technology in the wireless communications sector, made feasible the use wireless sensors. The wireless technology provides more flexibility, easiness of use and fast growth of sensors networks; although in certain critical applications there are data transfer reliability issues.
More analytically, the WSNs are constituted by one or more sink or base stations and by tens or thousands sensor nodes, which are scattered in a space. These nodes collect information from the environment and depending on the application, either process the information and send it to a central node, or they send it without processing. These nodes, usually sensor the temperature, the light, the vibration, the sound, e.t.c.. This information "travels" into the network, having as final destination the nodes sink. Depending on the application, sinks sent queries to the nodes, in order to gather useful information.
The most important advantage of this type of network is that, the beforehand knowledge of the topology is not required. This ability allows the rapid growth of networks in remotely and wild regions. The nodes have low cost and low consumption, as they have the ability of communicating in small distances, executing limited local data process and sensor signals of various types, in their application region. A sensor network is characterized from its lifetime, its expandability, its coverage, the production cost, the fault detection and correction, its synchronization, the response time, as well as the safety it provides. The storage energy capacity of the devices is the restrictive factor of life duration. It should be noted that the critical characteristic in a lot of applications, is not the average lifetime of one node, but the minimum estimated lifetime.
Training is a repeating (rollover) process consisting of four steps: assessment, planning, implementation,

and monitoring [2]. Overtraining is a non desirable process of excessive exercise training in high-performance athletes that may lead to overtraining syndrome. According author [3], overtraining syndrome is a neuroendocrine disorder characterized by poor performance in competition, inability to maintain training loads, persistent fatigue, reduced catecholamine excretion, frequent illness, disturbed sleep and alterations in mood state. In order to detect overtraining, the training load of each athlete needs to be monitored and individualized. Monitoring training load requires quantification of the intensity and duration of the physiological stress imposed on the athlete . Consequently, training volume and intensity are the basic training variables that characterize training load [4],[5].

Athlete monitoring is key to achieving both short term and long term competitive success. The more consistent the monitoring, the more meaningful the information will be. The increased athletic competiveness and at the same time the technology revolution, led to discover ways of monitoring the athletes training and performance. Monitoring each athlete data, such as heart rate, nutrition, provides useful information, enabling the personalization of the training, avoiding overtraining, which eventually lead performance maximization. In recent years, several wireless access technologies are broadening and changing our habits. Each wireless solution offers a specific mix of transmission band, costs, and coverage according to the needs that originated it.

A comparative study of the two technologies is given in [6]. The authors presented a broad overview of the four most popular wireless standards, Bluetooth, UWB, ZigBee, and Wi-Fi with a quantitative valuation in terms of the transmission time, data coding efficiency, protocol complexity, and power consumption. The performance analysis of the 802.15.4 standard has been extensively studied in the literature such as [7], [8], [9]. For instance, in [7] authors investigate the performance of the aforementioned network through simulations in the OPNET Modeler environment and came to the conclusion that the ZigBee protocol is well suited for monitoring athletes subscribers and similar applications.

In this paper, firstly an overview of the mentioned wireless protocols is presented. Following a performance evaluation comparison of the two standards in an soccer athletic field area is conducted using OPNET simulator, in order to investigate the more appropriate protocol for monitoring athletes vital signs by training. A specific scenario is analyzed and simulated and then network values such as end-to-end delay, traffic and throughput are exported. The rest of this paper is organized as follows. Tthe architecture of the protocols specified for wireless sensor networks is described in Sec. 2. Following that, Sec. 3 presents the simulation results achieved by using OPNET Simulator for Physical and MAC layer performance estimation. Finally, conclusions are given, offering quantitative evaluation of the proposed approach in Sec. 4.

2 Wireless Technologies Overview

2.1 Zigbee

IEEE 802.15.4 standard [10], determines the specifications of the Physical layer and the Medium Access Control (MAC) sub-layer of wireless personal area networks (WPANs) using devices they consume low power. ZigBee systems are being designed to provide wireless short-range communications (up to 100m), depending on power output and environmental characteristics.

WSN have particularly different requirements than standard local networks of ultra-high data transmission speed. It is reminded that devices like sensors are able to record and transmit information to environments inaccessible to human factors for particularly long periods. This implies that the design of each protocol related to them must take account of the following features:

a) the need for low power and energy consumption,

b) the need for self-configuration of the wireless network and adaptation thereof to the environment data, and

c) the signal “shielding” mechanism against interference, at physical level.

On another aspect, the high transmission speeds required in WLAN is of no particular concern, as the information usually transmitted relate to the recording of certain environment data (that is a few bytes of information) and not large volume files, as in the case of WLAN.

ZigBee specification focuses only on upper layers (Fig. 1): starting from the network layer to the final application layer, including the application objects themselves. The ZigBee application layer consists of the Application Support sub-layer (APS), the ZigBee Device Object (ZDO) and the manufacturer-defined application objects. The responsibilities of the APS sub-layer include maintaining tables for binding, which is the ability to match two devices together based on their services and their needs, and forwarding messages between bound devices. Another responsibility of the APS sub-layer is discovery, which is the ability to determine which other devices are operating in the personal operating space of a device [11].

Wireless connections under 802.15.4 standard can operate in three ISM (Industrial Scientific Medical) frequency bands with the following data rates:

1) 250kbps in the 2.4 GHz band (O-QPSK encoding),
2) 40kbps in the 915 MHz band (BPSK encoding) and
3) 20 kbps in the 868 MHz band (BPSK encoding)

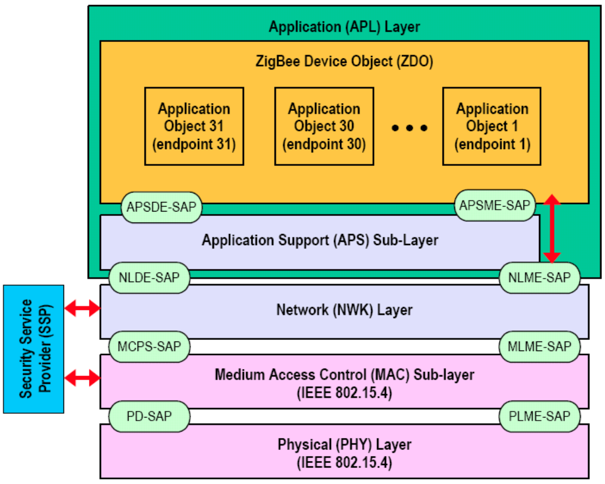

Fig. 1 ZigBee Communication Stack

2.2 The WI-FI standard

Wireless Local Area Networks (WLANs) are one of the internet-related technologies that during the last decade marked the greatest expansion at global level. The replacement of analog lines with digital ones, the expansion of optics communications (fiber optics), and the increased information transmission rates occurred in parallel to the replacement of certain wired functions by wireless ones. Currently, every household, or work area with internet access supports a wireless network through the router antenna and the wireless network card of a laptop. Therefore, it is obvious that any design – at least in an urban environment - of a network other than WLAN, such as those of 802.15.4 which operate in the same frequencies and at a lower transmission strength, must take into account the interference caused by wireless local area networks.

IEEE 802.11 protocol defines two types of equipment (Fig 2), a wireless station, which is usually a PC equipped with a wireless network interface card and an access point acting as a bridge between the wireless and wired areas of the network. The access point usually consists of an antenna, a wired network interface and a software that responds to protocol 802.11d, which “transfers” data from the wireless to the wired network. Access point operates as a base-station for the wireless network, allowing multiple terminal devices connection to the wired network. IEEE 802.11 standard defines two operating modes: (a) infrastructure mode and (b) ad hoc mode [12]

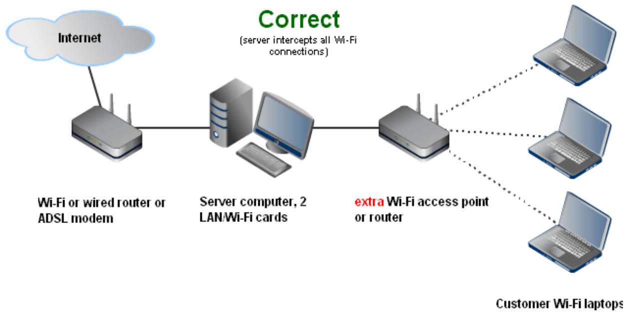

Fig. 2 Wi-Fi network topology

Wi-Fi standard defines the following networking topologies:

- IBSS (Independent Basic Service Set) or ad hoc topology

This is the most simple wireless network topology (Fig. 3). The stations are peers and communicate directly between them, peer to peer, without a central station. This networking mode is used primarily by small networks. A necessary precondition for the communication between two stations is that each one is within the range of the other.

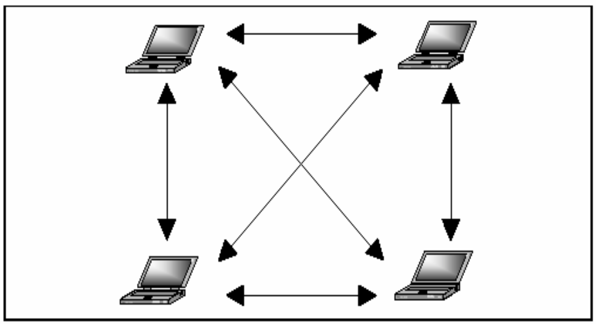

Fig. 3 IBSS topology

- Infrastructure

BSS topology is a more complex networking topology in which the wireless network has cluster form. In each cluster there is a number of wireless

stations (clients), which communicate between them through a central distributor BS (Base Station) or, more commonly, AP (Access Point).
There is determination of two service types, depending on the number of Aps, and therefore the number of clusters [13]:
a) Infrastructure Basic Service Set.
b) ESS, Extended Service Set

A wireless network can also consist of more than one clusters, which can be bridged over a Distribution System. The distribution system is the network connecting APs between them and with the other networks. The entire interconnected network, including the distribution system and the APs constitutes the ESS topology. That is, it is a set of clusters, each one of which consists of an access point AP, with all APs being connected to a network structure. This achieves larger wireless coverage range. In this case, each wireless station can commute from on cluster to the other without the station itself, or the network experiencing any change. This ability of the network is called roaming.

IEEE 802.11g protocol operates on the same bandwidth with 802.11b, namely 22MHz, which allows it to achieve higher transmission speeds. Moreover, depending on the environmental noise, the protocol is able to select among new operation speeds which are 6,9,12,18,24,46,48,54Mbps. In addition, it is compatible with 802.11b as it can also support 1, 2, 5.5 and 11Mbps speeds using DSSS and CCK encoding. The need to increase transmission speeds while maintaining bandwidth at 22MHz, in conjunction with the resistance of the system to intersymbol interference, were the key parameters for the use of a new configuration, OFDM (Orthogonal Frequency Division Multiplexing). New speeds (6,9,12...54) are the result of OFDM configuration. OFDM is the sole configuration able to achieve high transmission rates while resisting interference. The following table depicts the frequency bands and the theoretical and actual speeds of the various 802.11 standards [14]

Table 1 The frequency bands of 802.11 standard

Standard	Frequency Band	Typical Transmission Rate	Theoretical Transmission Rate	Range Indoors
802.11a	5GHz	23Mbps	54Mbps	35m
802.11b	2.4GHz	4.3Mbps	11Mbps	38m
802.11g	2.4GHz	19Mbps	54Mbps	38m

3 Simulation Results

3.1 Simulation model description

OPNET Modeler [15] constitutes a specialized tool in the area of communications, having graphic environment for modelling and simulation, of various types of networks. The platform allows the design and thorough study of telecommunication networks offering great flexibility depending on the layer of the network concerned. Moreover simulating separate models for each network, it is possible to take measurements of global and object parameters, such as packet delay, packet loss, throughput, e.t.c. and through them can export general conclusions of the systems performance.

The main objective was the development and study of the two communication networks between athletes and coordinator (coach). The area selected for the simulation was a typical soccer field. The length of a full-size soccer pitch must be between 100 yards (90 metres) and 130 yards (120 metres) and the width between 50 yards (45 metres) and 100 yards (90 metres) with 11 players. Each of the 11 players was able to move in a specific territory clockwise in a parallelogram trajectory round the area depending on its playing position. For example, a Goalkeeper player, can move along the sidelines of the playing area near the goalposts (Fig. 4 and Fig. 5). The subscribers are moving with different speeds (10 to 15 Km/h). The scenario primary objectives were the recording of the communication link between the nodes and the coach, the collection of the identification and status data transmitted over a short period of time for each network topology whereas depending on the results, conclusions would arise regarding each protocol's performance.

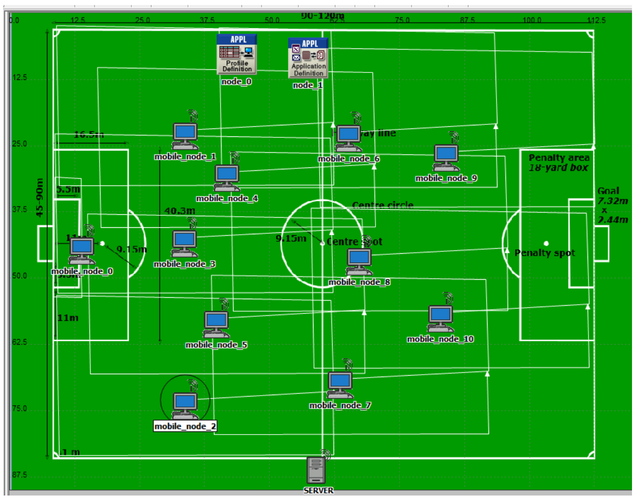

Fig. 4. Geographic positioning in simulation environment for WLAN IEEE 802.11g protocol

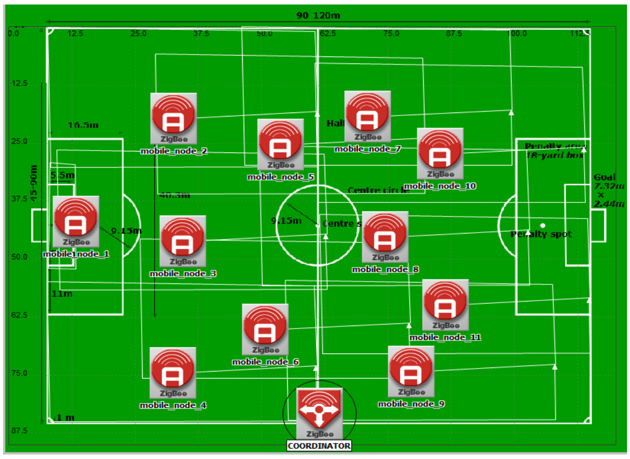

Fig. 5 Geographic positioning in simulation environment for ZigBEE protocol.

At the beginning, mobile stations of the network were requested to send a large amount of information related to their status. For this reason, in the simulation model, the size of packets transferred via Database Access application was set to Medium Load. The duration of the simulation was selected to be 10 minute due to the amount of data required to be processed. Data rate was set to 250 kbits/second in the 2.4 GHz for ZigBee and 54 Mbits/second in the same frequency band for 802.11g.

3.2. Results

One can collect values from individual nodes in the network (node statistics) or from the entire network (global statistics). Global statistics can be used to gather information about the network as a whole. Node statistics provide information about individual node such as coordinator, router or end device. The eleven nodes in the athletic field topology were identical. The Global Statistics of the network, whose graphs will be examined, are listed and analyzed in the following:

- *End to End delay (sec)*: is the time that lapsed between creation and reception of an application packet.
- *Throughput (bits/sec):* Represents the total number of bits (in bits/sec) forwarded from wireless LAN to higher layers in all WLAN nodes of the network.

The Node Statistics for the Coordinator and one node (player 5) of the network are analyzed below:

- *Throughput (bits/sec):* represents the total data traffic in bits/sec successfully received and forwarded to the higher layer by the WLAN.
- *Data traffic received (bits/sec):* represents the average number of bits per second for traffic successfully received by the MAC from the physical layer. This includes retransmissions.
- *Data traffic sent (bits/sec):* represents the traffic transmitted by the MAC in bits/sec. While computing the size of the transmitted packets for this statistic, the physical layer and MAC headers of the packet are also included.

The results and graphs are presented in the following Figs 6-10. Fig. 6 demonstrate the end to end delay of the network for the 802.11g (blue curve) and ZigBee (red curve) technologies respectively. As a result, the delay is higher in ZigBee than in 802.11g. The main reason for this is the different data rate according the used technology. The next graph (Fig. 7) represents network throughput (bps). It can be seen that throughput is heavily influenced by the traffic load since none of the networks achieves theoretical transmission values and 802.11g performs better. Similarly results can be obtain for Fig. 8. It can been observed that WIFI throughput is higher and coordinator does not accept packets until the pending data are not completely transmitted avoiding collisions situations. Fig. 9,10 represents traffic received and sent (bits/sec) values for coordinator and node 5 player. In both cases, it is observed that WLAN technology continues to perform better. Fig. 11 and 12 also shows that all nodes have more or less equivalent traffics. Taking everything into account 802.11g provides fast networking connections and outperform the other standard.

4. CONCLUSIONS

The objective of this paper is to examine the performance of the IEEE 802.11g and IEEE 802.15.4 standards for wireless sensor networks applications. At the beginning an overview of the two wireless technologies adapted in monitoring vital signs of athletes, mainly during training is presented. Furthermore through simulations in OPNET Modeler environment global and node statistics in soccer field area with eleven nodes is examined. The trajectory on each mobile node is configured on specific destination round the field. According to simulation results the 802.11g protocol tends to outperform IEEE 802.15.4 protocol mainly due to its high transmission rate. More specific it gives less network end to end delay and higher average throughput.
In the future authors intend to perform further experiments in order to examine power consumption and energy efficiency of the two technologies.

ZigBee's lower data rates, can support much lower power consumption rates. Extending this work authors will develop the whole physical layer transmitter and receiver for the two protocols using Nallatech XtremeDSP Development Kit with Xilinx FPGA for real time implementations and study the theoretical model variation.

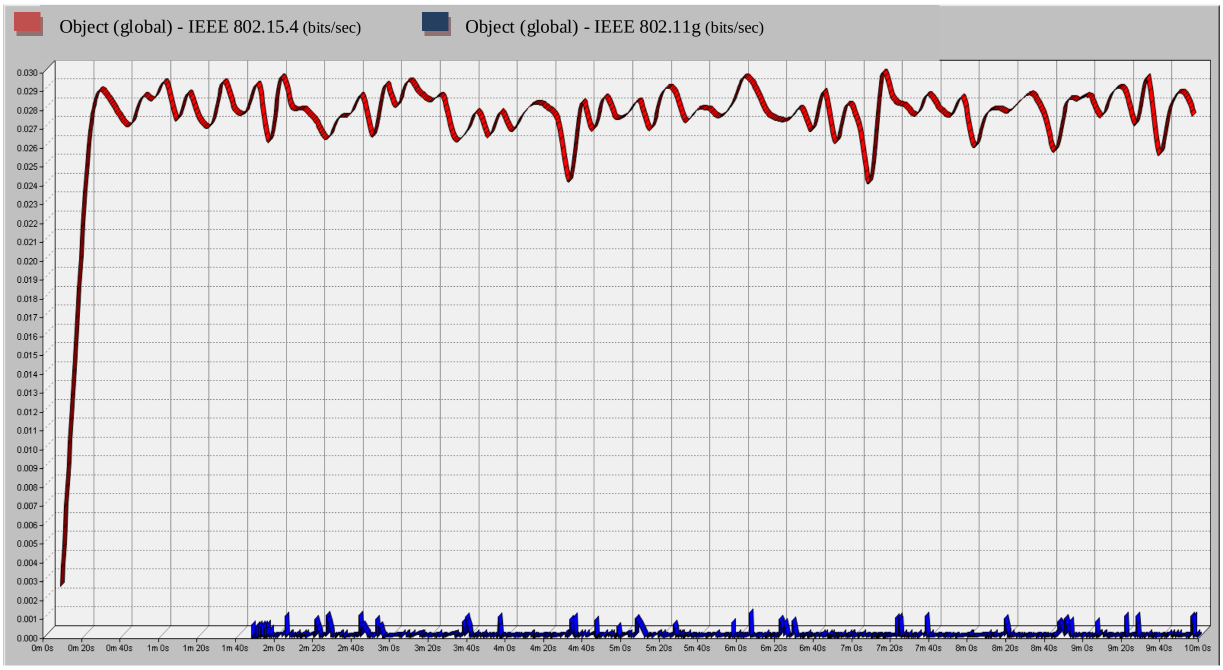

Fig. 6. Global statistics - end to end delay (sec) comparison for both protocols

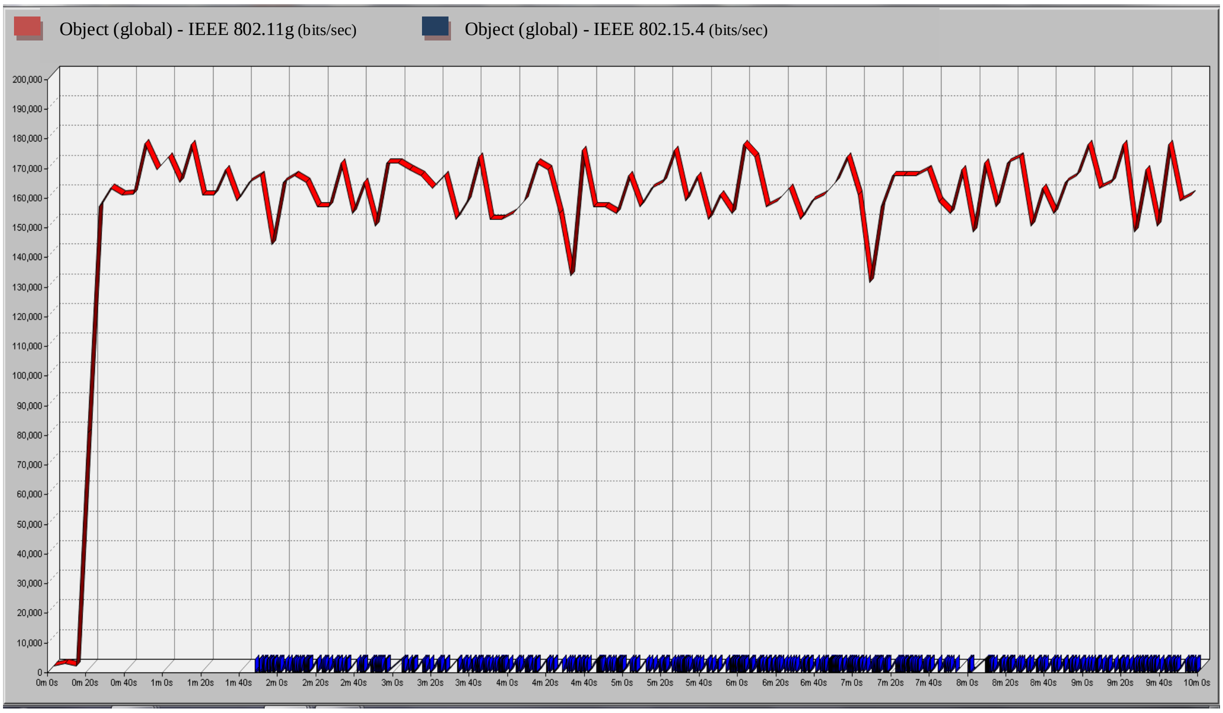

Fig. 7. Global statistics – Throughput (bits/sec) comparison for both protocols

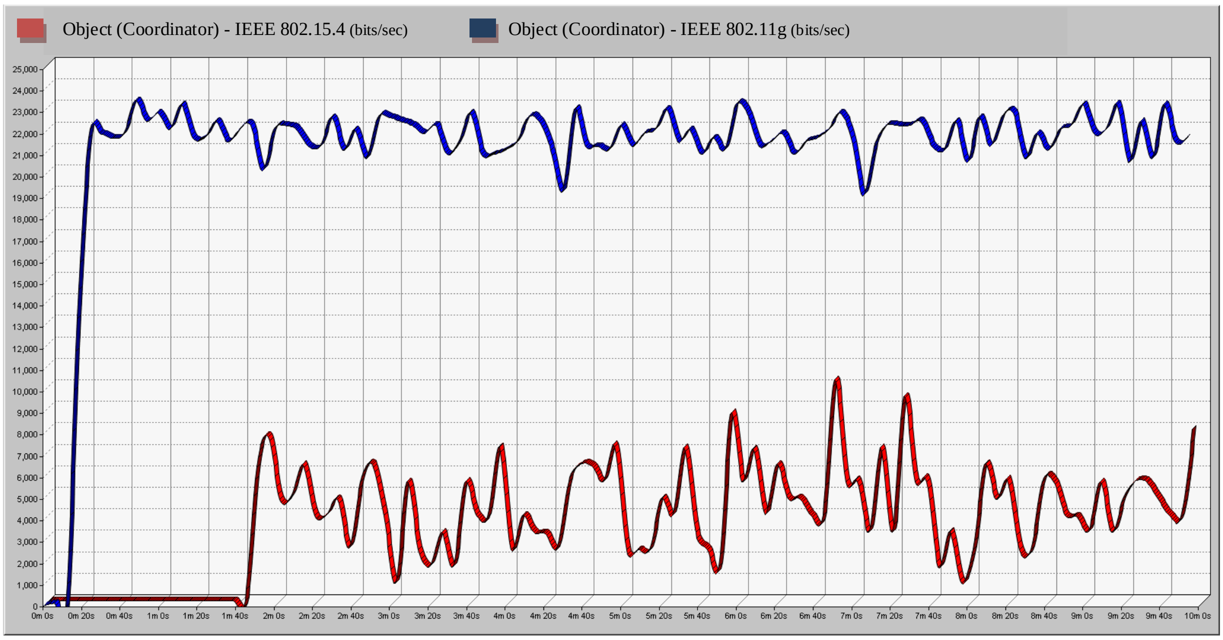

Fig. 8. Coordinator statistics – Throughput (bits/sec) comparison for both protocols

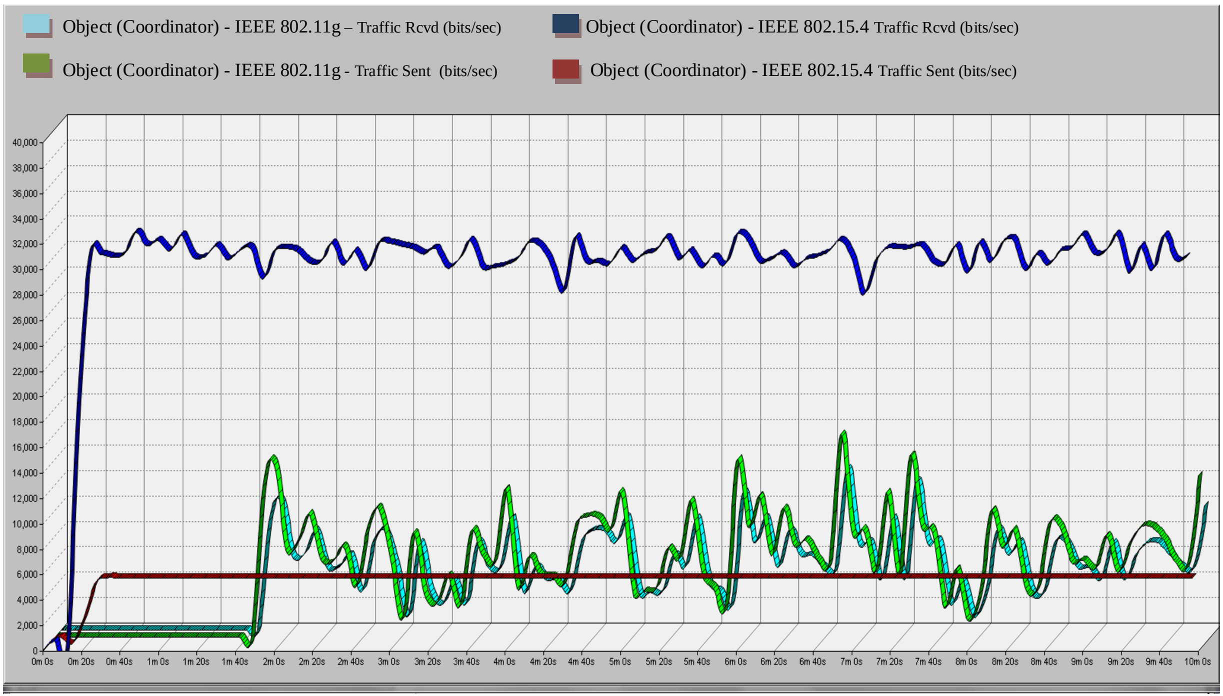

Fig. 9. Coordinator statistics -Traffic received, Traffic sent (bits/sec) comparison for both protocols

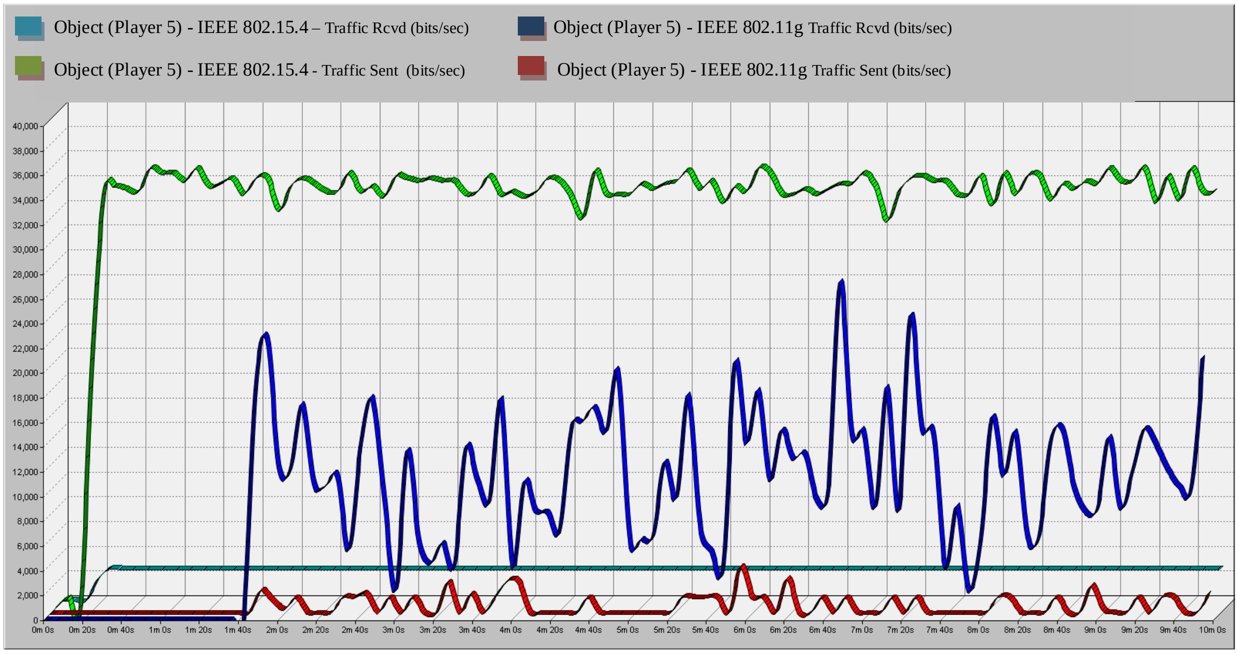

Fig. 10. Player 5 – Router device statistics - Traffic received, Traffic sent (bits/sec) comparison for both protocols

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