A Wireless Sensor Network for Soccer Team Monitoring

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Abstract—**One of the most desirable issues in team sports is to know how the physical state of each sportsman or sportswoman is performing during the match. Concretely, a soccer match is 90 minutes long and the players could be more or less tired depending on the dynamic of the soccer game (fast or slow) and on the place where the ball have been rolling (which affects more to one users than others). This paper presents a wireless sensor network proposal for soccer team players' remote monitoring. Each player has a wireless body sensor and each player will be a sensor node in the wireless sensor network. The approach allows knowing the physical state of each player during the whole match. In order to have fast updates and larger connection times to the gateways, the information can be routed through the players of both teams. We focus our study in the network topology and in the mobility model of the soccer players.**

Keywords- Wireles Sensor Network; Wireless Body Sensor Network; mobility; soccer.

I. INTRODUCTION

Body area networks (BAN) and Wireless Body Area networks (WBAN) emerged as a technology for health monitoring [1]. Their main uses are focused on sensing biometrical parameters by means of wearable devices from target individuals for both monitoring actual medical episodes and preventing further complications. Some of these biometrical parameters are, but not limited to, hearth rate, temperature, blood pressure, etc. Furthermore, BANs can be used to collect athletes' data for performance assessment and/or improvement. BANs can be accomplished by means of off-line processing of the data collected from the athlete sensing system. There are several works in the literature that give us an overview of the wide range of applications. An example given about how to monitor fetal movement during a woman's pregnancy is shown in [2].

Smaller integrated circuits and embedded devices, new technological advances in miniature biosensing devices, small physiological sensors, transmission modules and processing capabilities, made possible the appearance of new wearable sensor systems for health, mental and activity status monitoring.

Zigbee is the wireless technology commonly used in WBANs. It was developed to address the needs of small, low-cost, and low-power wireless networks. Its standard has been specified in IEEE 802.15.4 [3] and it operates in unlicensed bands including 2.4 GHz, 900 MHz and 868 MHz. It is a packet-based radio protocol that allows devices to communicate in a variety of network topologies and can have a long live battery (even for several years).

WBAN systems have to ensure seamless data transfer across ZigBee to promote information exchange and plug & play device interaction. Furthermore, the systems should be scalable, ensure efficient migration across networks and offer uninterrupted connectivity for personal and individual healthcare.

In this paper, we make use of WBANs and propose a WSN that allows the interconnection of WBANs placed en each soccer player. The mobility of the soccer players will permit to transmit their physical state while they are playing the soccer game.

The paper is organized as follows. Section 2 details some related work of this field of knowledge. Section 3 presents the proposed system architecture. The mobility model, the analytical assumptions and the routing protocols used in our proposal is described in Section 4. Section 5 provides the simulation results. Finally, our conclusion and future work are shown in Section 6.

II. RELATED WORK

This section is divided into two main parts. The first one is focused on group-based topologies and mobility models, while the second part is focused on the research on biosensor systems for athletes or for any sportsman or sportswoman. In this last case, athletes, sportsmen or sportswomen become ad hoc network nodes that need to transmit and relay information from their own sensors or from other players to sinks nodes. This novel application requires new mobility models, which follow accurately the paths of the players in the field during the match, as well as reliable routing protocols.

When several teams or groups of people should be monitored at the same time, a group-based topology must be used. Moreover, each group could have different topology [4]. In this paper, we consider that groups are located in the same place and a node can only belong to one group. An example of how groups can be created and could coexist in the same place is shown in [5].

In [6], T. Camp et al present a survey of mobility models that are used in ad hoc network simulations. They describe individual mobility models and group mobility models. The models are classified in traces and synthetic, and they focused their work in the second type. Their results show the importance of choosing a mobility model when an ad hoc protocol is simulated. Most of these group models could be a reference-point for modeling soccer player's behavior.

There are some works related to the sensing of physiological data from professional sport practitioners, but most of them rely on off-line data analysis. Next works show how some systems allow real-time monitoring. There are also some experiences where athletes and soccer players are monitored.

In [7] and [8], A. Pantelopoulos and N. Bourbakis present two surveys on wearable biosensor systems for health monitoring. They compare a variety of system implementations and approaches. They study a set of significant features and identify their technological shortcomings.

A body area sensor network for monitoring soccer players in a soccer field is presented in [9]. They show their design and discuss the choices taken for their proposal. Because of the high delays for direct transmissions from the soccer players to the base stations, they propose a multi-hop routing protocol that balances between the competing objectives of resource consumption and the delay.

A group mobility model (called DynaMo), that takes into account the interactions between players and the expected trajectories of players during a soccer match, is presented in [10]. Each player wears a BAN that collects and transfers data to a sink node by means of inter-BAN multihop routing. The impact of the mobility on the network performance is analyzed in terms of throughput and delay. Moreover, the model is compared with existing solutions (such as the Reference Point Group Mobility model) by analyzing the generated mobility patterns.

In [11], the authors conduct several field experiments with sensor devices to record the inter-connectivity of soccer players during a real game. They show that the wireless topology in the soccer field is in general sparse, with short encounters and power-law distributed inter-encounters. Coordinated movement of players gives significant correlations amongst links, which could be exploited by real-time routing algorithms.

Our proposal not only takes into account the mobility model, but also the topology of the nodes in the wireless sensor network, which is given by the team formation system. Moreover, all the works presented in this related work section, tackle the problem as there were only one team, and our WSN proposal is designed to work using both teams simultaneously.

III. System Architecture

Our goal is to get biometrical, physiological, or in a broader sense, general health data from soccer players during a match, or a workout, in order to know which the physical state of each one is during the entire match. It will allow us to see if there is a tired soccer player, and let the coach to monitor remotely the soccer team players. In order to achieve our goal, each player has a wireless body sensor and each player will act as a sensor node in the wireless sensor network. How the data is taken from the body and the way used to gather them are out of the scope of this paper. We will assume that there is a biosensor in the market that is able to provide this information (this assumption will be taken after we see that this biosensor can be bought in the market).

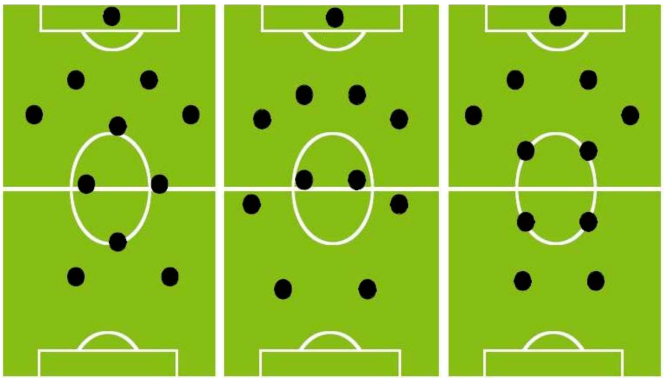
It is important for the athletes that both the sensing and the transmission system should be non-intrusive and light-weighted because in high level sport competitions every simple detail can make a big difference. This requirement leads us to use low power radio devices that implies low transmission range.

In our approach, every single player on the field is a WBAN that can generate data to transmit or relay data from other nodes in the WSN. This architecture is based on inter-WBAN data communication. These data will be routed from a mobile source to a fixed sink located outside the game field. There is no preferred place to fix these sink nodes, although we have chosen our locations behind the goals. The rationale behind this choice is that some team players are likely close to one of the goals most of the time (at least the goal keepers), so they will be under the coverage area of the sink nodes.

In our proposal, from the network point of view, there is no distinction between teams. Every node (player) is a next-hop candidate, and thus both teams use the same infrastructure in order to receive data from their players. So, the information can be routed through any node, but the data must not be merged and all information transmitted to the network belongs to the team of the source node and must only be understood by that team. This system characteristic will imply the use of data encryption and user authentication for privacy. The system will allow fast updates and larger connection times to the sink nodes.

The soccer player's formation and the way they move on the field determine the effectiveness of the whole system. It is important the use of an accurate topology and mobility model.

The size of the field can vary from 100 meters to 110 meters long and from 64 meters to 75 meters wide it depends on the country and the world zone). There are two teams with eleven players. Their formation and the number of players in each line depend on the strategy of the coach. Some formation is better when the pretend to attack and others are better to defend. Every location is known as a position. Positions are grouped by lines. These lines are named as: goalkeeper, defenders, midfielders and forwards. Except goalkeeper line that is formed by a single player, the rest can be formed by a number of players that can vary between matches or during a single match due to tactical variations. From our research perspective, this formation will determine the topology of our WSN. Figure 1 shows the most common team formations, which will be our base WSN topology. They are named 1-4-4-2 rhombus, 1-4-4-2 line, 1-4-4-2 square, 1-4-3-3, 1-4-2-4, and 1-3-5-2 formation respectively. There are others such as 1-5-3-2 and 1-3-3-4 which are not so shown. These topologies provide us the most probably location where each node will be placed and we can also can estimate the area where they will most probably be moving during the match.


a) 1-4-4-2 rhombus b) 1-4-4-2 line c) 1-4-4-2 square.

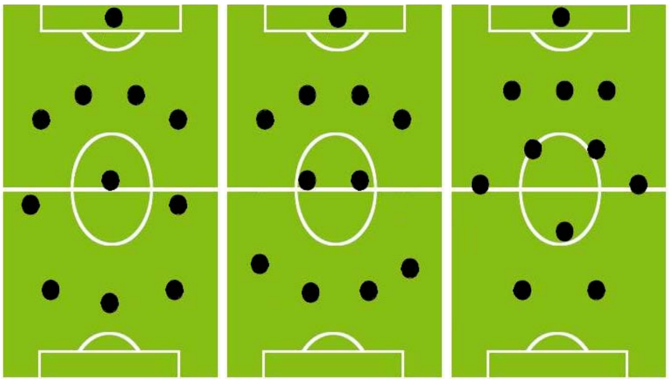

d) 1-4-3-3 e) 1-4-2-4 f) 1-3-5-2.

Figure 1. WSN topologies.

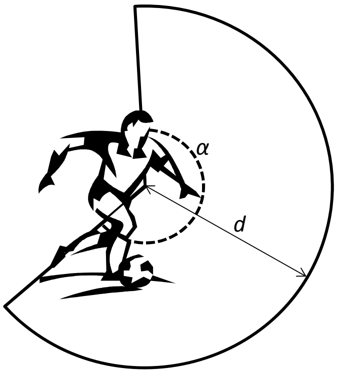


Figure 2. Radio coverage of each player.

The most common model used to estimate the radio coverage of a node is the disk model, which assumes that the radio region is a circular area centered on it. Any node placed closer than the radio coverage d will be a neighbor. d is determined by the transmitter and receiver power and the antenna gains. When the node only covers an area (not the whole circle), because of the type of antenna or because a part is hidden by the body of the soccer, the receiver must be located inside the angle of the transmitter's coverage area. The area inside a partial circle bounded by a radius r and an arc α is provided by equation 1.

$$Area = \frac{1}{2}d^2 \cdot (\pi \cdot \frac{\alpha}{180} - sin\alpha) \quad (1)$$

Where d is the circle radius and α is the angle (in degrees).

Figure 2 shows the partial circle area covered by a football player.

In order to provide security, each team has a pair of team keys (a public team key and a private team key), which is shared by all players of the same team, and must not be ever discovered by the other team, and a game key that is the same for both teams. For the pair of team keys we use asymmetric encryption, while for the game key we use symmetric encryption. Every time, a new player joins the game, it has to authenticate with the first player it finds when it goes into the field. In the authentication process, the new player sends the game key encrypted with the public team key. Only the players of the same team will be able to decrypt it with the private team key and will be able to check if they have the same game key. If they have the same key the new player is authenticated and will be able to join the wireless network. Now every time a node sends information to the sink node, it first encrypts with the public key of the team, and then with the game key, then when the data is sent to another node, any node in the match will be able to decrypt the information, and route to the appropriate sink node (to its sink node if it is from a player of its team or to the sink node of the contrary if it is from a player of the other team).

IV. Mobility Model

In this section we are going to explain the mobility model. It has been divided in three parts. The first one explains the zone model, which is the zone in which each player is moving, the second one explains the group mobility model, which let us know that players try to move behind the ball, and the third one which explains the routing protocol used in our proposal.

A. Zone Model

We define a probabilistic model for players' location. In steady state, at the beginning or after a defensive withdrawal, the players draw the team topology on the field (see Fig. 1).

Every player will move on the field within an area that will be position dependent. A two dimension probability density function (PDF) position associated exists. We will call this function "the locator". Given a couple of coordinates x and y, a position locator returns the probability of finding the player associated to the position at that point. Equation 2 shows the PDF function.

$$P[a \le X \le b, c \le Y \le d] = \int_a^b \int_c^d f_{X,Y}(x,y)dxdy \quad (2)$$

A default locators library is created, and every entry in the library will be assigned to a position. New positions will be added to the library as needed, and it is feasible to have more than one entry for a given position.

B. Group Mobility Model

Our group mobility model is based on Pursue Mobility Model [6]. This model represents players tracking a target: the ball. The target can have its own individual mobility model.

The model has an update location formula for each player which is shown in equation 3.

$$p_l = p_{ol} + acceleration(b_l - b_{ol}) + random\_vector \qquad (3)$$

Where p_l is the player updated location, p_{ol} is the player old location, b_l is the ball updated location, b_{ol} is the ball old location, *acceleration*(b_l – b_{ol}) is needed to follow the movements of the ball, and, finally, *random_vector* is calculated from an individual player mobility model.

Our proposal add the estimation of the *random_vector* out of the locator from our zone model, because in real soccer games, the movements of the players are ball position dependent combined with the player position in the team topology. Additional refinements in the model can be applied. One of these improvements could be the use of gravitational models. With the use of these models we could model the action of a defending player over an attacking that is driving the ball in that moment.

C. *Zigbee Routing*

In order to provide routing in the WSN, we used the ZigBee Routing Protocol (ZRP), which is defined in the standard. It is based on AODV (Ad Hoc On Demand Distance Vector), which is a reactive routing protocol, by default and Hierarchical Tree Routing as last resort. In [12], there is a performance analysis of ZigBee Routing Protocol. It shows that Hierarchical Tree Routing provides shorter average end to end delay but performs poorly in terms of energy consumption. So, in our case, for supporting real time communication, it is desirable to choose Hierarchical Tree Routing.

V. SIMULATIONS

In this section we present the simulations performed in our proposed system.

A. *Test bench*

The simulations presented below were performed using the OPNET simulator [13]. We have created an environment with the characteristics of a football field. The football field has a size of 110x70 m^2. Players on each team are placed in the initial position shown in figure 3. From this initial topology we have made 3 simulations, one when players are not moving, another one when the players have low movement, and, finally, a simulation where players have high mobility.

In the simulations we have located two sinks behind each goal we thought it is the best situation, because the goalkeeper can always serve as a liaison between the players and the sink. The information comes from sensors located at players, besides they send information to the sink. The sink will collect this information, which will send it by using another wireless or wired technology to the team bench in order to let the coach and the trainers know how the players are. It will allow them to have updated information about the players in the field.

In our simulation, nodes communicate using Zigbee in the 915 Mhz frequency band. The traffic injected into the WSN follows an exponential distribution with an average packet size of 1024 bits and an inter-arrival time of 10 seconds. We believe that to use an average of 10 seconds is appropriate because there is no need of monitoring these events with higher accuracy.

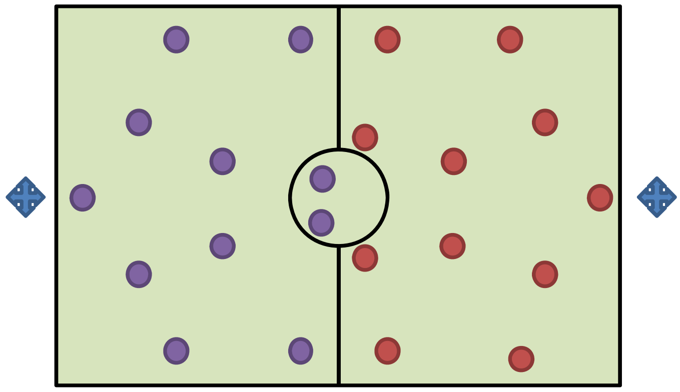


Figure 3. Test bench topology .

B. *Load per team*

In figures 4 and 5 we can see the load of the network per team. In figure 4, the load of the team A is shown. In this figure we can see that the behavior of the traffic is quite variable. The average load when the players have high mobility is around 25 Kbps, however when our system has low mobility or it is static, the load is 56.5 Kbps and 57.8 Kbps respectively.

On the other hand, in figure 5 we show the same parameter of figure 4, but in this case it is from team B. Figure 4 is different of figure 5 due to the movement of the players. In this second case, when the players have a high mobility, the load of the network is around 26 Kbps, this load increases until 50 Kbps when the mobility is low and finally the load is 58 Kbps when the players are static.

According to these figures we can say that our proposal works better when the topology has high mobility because the network load is lower.

C. *Control and management traffic*

In figure 6, the control traffic needed by all network in order to manage the correct running of the system is shown. When we have high mobility the traffic is around 7 Kbps. But this traffic is quite higher when the nodes of the topology are static or when they have a low mobility (around 25 Kbps).

The control traffic is needed in the network, but if it is too high, it means that the network has not a right behavior. In our system, we can assert that our system runs better when the nodes have high mobility (it has 28% of improvement). In a football match this behavior is common, so our proposal is quite adequate for this type of sports, where the players have many movements.

The figure 7 shows the topology management traffic. This traffic is needed by the network in order to know the changes of topology. It helps the network because the nodes need to know which their best neighbor to transmit its information is. When the topology does not have movement or it is low, the management traffic is 2 kbps but only during the first seconds, then, it is around zero. However, when we have high mobility this traffic is constant and it is around 400 bps. In both situations the management traffic is low, so for this reason we say that the proposed system runs well.

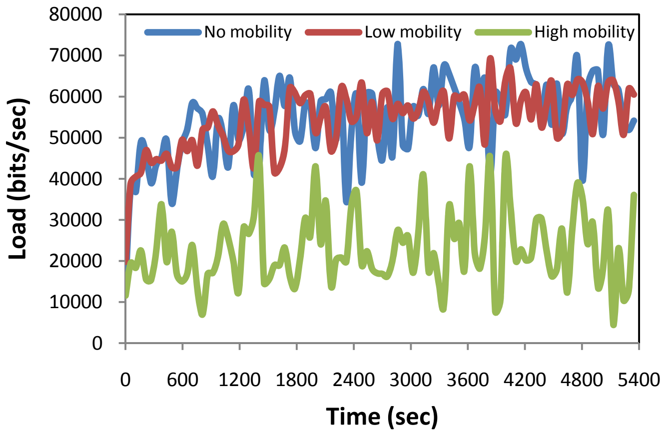


Figure 4. Load (bits/sec) of the team A.

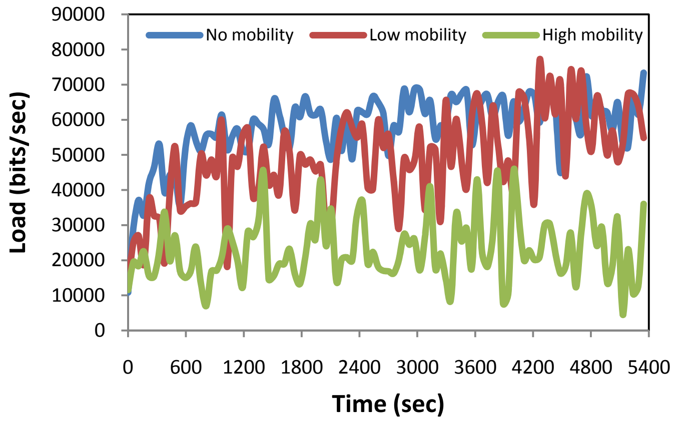


Figure 5. Load (bits/sec) of the team B.

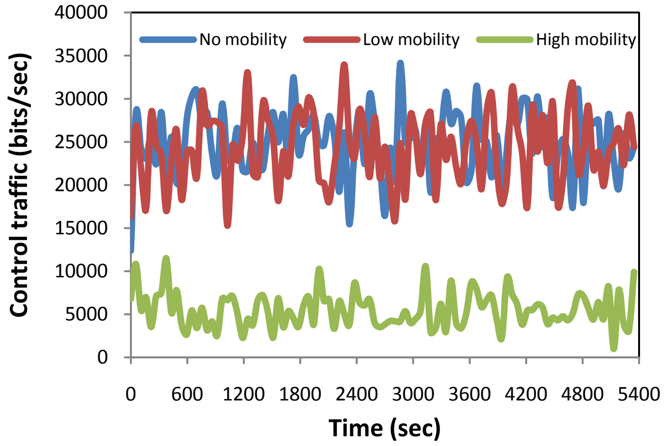


Figure 6. Control traffic (bits/sec).

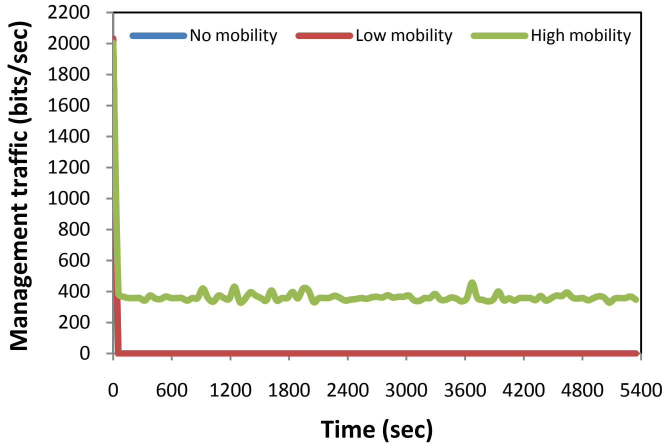


Figure 7. Topology management traffic (bits/sec).

D. Delay

The delay of the network is presented on the figure 8. In this figure we can observe that its behavior is constant during the simulation time. This behavior could be unsuitable for a network, but in this case it could be accepted because the delay is 4 seconds in the worst case (without mobility or low mobility). This delay is accepted because the network requirements are not very strict. This delay would not be acceptable if we need a real-time network.

When our network has high mobility the maximum delay decreases until 2 seconds. So, our system is better, in terms of delay values, when the nodes have high mobility.

E. Hops needed per team

Finally, in figure 9 and 10 we analyze the probability dense function of the average number of hops needed by the teams A and B.

In figure 9, we show the probability for the team A. In this case the probability to need 4 hops to reach the sink is 0.7 with low mobility, but this probability decreases when there is higher mobility. That is, with higher mobility this probability increases according to the number of hops, so it is more probable to need more hops to reach the sink. It happens because the network is changing continuously. Thus, it is more difficult to find a good path to arrive to the destination. In the team A (high mobility) the most probable will be 16 hops per route.

The same behavior occurs with the team B (see figure 10). In this case, the static topology and the low mobility have a similar behavior. In both cases the most probable is to need more than 9 hops to arrive to the sink. When the topology has high mobility the most probable is to have between 11 and 14 hops per route.

According to this behavior we can say that our proposed system is feasible and performs well even in high mobility. Although it needs more hops to reach the sink node when there is high mobility.

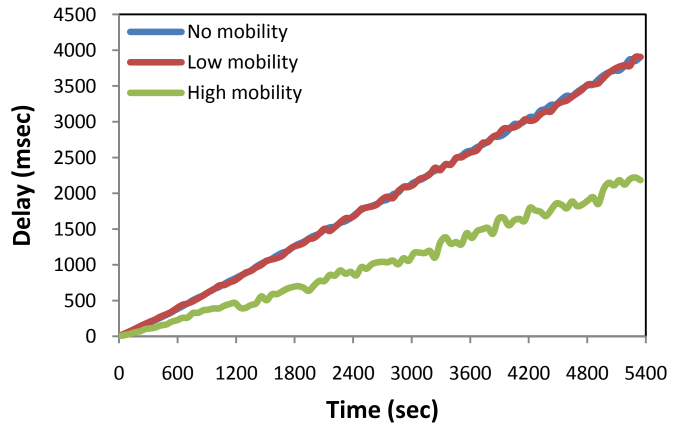


Figure 8. Delay of the network (msec).

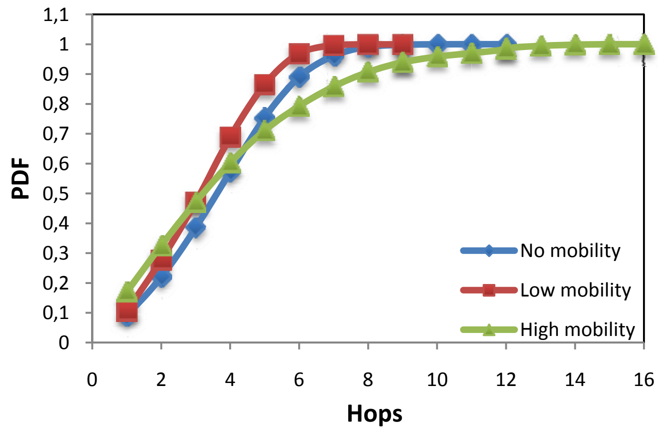


Figure 9. Probability dense function of the # of hops (team A).

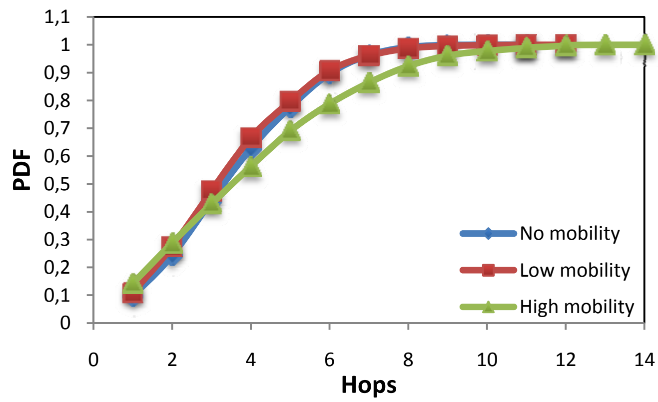


Figure 10. Probability dense function of the # of hops (team B).

VI. CONCLUSION

In this paper we have presented a new way to transmit the information gathered from the wireless body sensors placed in the football players. That is, the information can be routed though the nodes of the same team or through the nodes of the other team, but the information can be only decrypted by players (and the coach) of the same team.

Our simulations show that the network load is lower with high mobility, but it needs more hops when there is high mobility. In both situations, low mobility and high mobility, the management traffic is low.

We are now developing the devices in order to measure our proposal in a real soccer game.

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