Mobility model for Body Area Networks of soccer players

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Abstract— **This work proposes a novel group mobility model that takes into account the interactions between players during a soccer match in order to generate realistic mobility patterns. The model is compared to existing solutions by analyzing the generated mobility patterns and their resemblance to the expected trajectories of players during a match. The analysis highlights the capability of the proposed model to generate realistic patterns. The proposed model is then adopted to represent the movement of players in an application scenario where each player wears a Body Area Network (BAN) that collects and transfers data to a sink by means of inter-BAN multihop routing. The impact of mobility on network performance is analyzed in terms of throughput and delay. Results highlight that different mobility models lead to significantly different network performance, and confirm the need for accurate mobility models in the analysis of wireless mobile networks.**

I. Introduction

Body Area Networks (BANs) consist of a number of wireless sensors located on the human body, or in close proximity such as on everyday clothing [1]. Application scenarios for BANs were originally mostly limited to monitoring still or slow moving subjects, e.g. patients in medical facilities [2], [3]. Advances in wireless technology are, however, progressively widening the range of possible application scenarios for BANs [4], [5]. The feasibility of BANs for monitoring of professional athletes in several sports for both health care and advanced training has been, in fact, intensively investigated [6], [7], [8]. This work focuses on mobility models for soccer matches.

Tipical solutions for team sports focused on the extraction of player mobility patterns by means of image processing and tracking techniques to be applied to pre-recorded matches [9], [10]. This approach suffers however of two drawbacks: 1) this information cannot be used in real-time, and 2) no biomedical information is collected. The adoption of BANs potentially equipped with GPS can address such issues. BANs offer the unique possibility of acquiring real-time biomedical information, such as heart and breathing rate, and of combining it with information on position, speed and mobility patterns for each player in the team. This opportunity opens new, unprecedented possibilities for trainers and team managers, and provides the guidelines to set a new standard for match and training sessions analysis.

Network protocols should be able to react to, and possibly take advantage of, the varying inter-BAN connectivity [7]. As a consequence, an accurate performance analysis of BANs requires the capability of modeling all key aspects characterizing the scenario, in particular the mobility patterns of players, potentially affecting the connectivity between BANs and, in turn, the performance of algorithms and protocols at MAC and network layer.

The definition of specific interaction rules between players is of primary importance to obtain accurate mobility patterns. The comparison with real mobility tracks highlights the need for a more accurate modeling of players behavior [11]. In this work a novel mobility model, named DynaMo, is proposed. DynaMo is capable of modeling both individual movement patterns and group mobility behaviors.

The DynaMo model is used in this context to represent the mobility behavior of players during a soccer match, via a proper definition of group constraints able to reflect the dynamics of a soccer team, in terms of roles of the players in the team and of their reactions to the mobility behavior of team mates and opponents.

DynaMo is compared against the Reference Point Group Mobility (RPGM) model [12] in terms of accuracy in generating realistic player mobility patterns in soccer matches, by comparing the patterns with the expected positions of players during a match according to their role in the team. Comparison is also carried out with respect to the impact on network performance, by measuring end-to-end throughput and delay for multihop inter-BAN comunications.

The paper is organized as follows. Section II presents the DynaMo group mobility model. Section III provides details about BANs organization. Section IV compares the mobility patterns generated by the Dynamo model with those obtained using RPGM, while Section V analyzes the impact of the two models on network performance. Finally, Section VI draws conclusions.

II. The DynaMo mobility model

The foundation of the DynaMo mobility model lies on the observation that group mobility is often the result of decisions taken by individual entities, that modify their own mobility patterns depending on the behavior of other entities. As a result, the mobility patterns of entities of the same group originate from the combination of individual mobility and group constraints. The DynaMo model mimics this behavior by allowing each entity in a group to move around freely as long as the group internal requirements and a set of external constraints are satisfied.

DynaMo applies this approach by imposing on one side a condition of physical proximity between a node and the other nodes of its group, and on the other side a set of proximity conditions between a node and a number of entities acting outside the group. If all these conditions are met, the node moves according to a standard mobility model, otherwise the node modifies its behavior in order to move as fast as possible towards a position in line with the set of constraints imposed by the model.

As a consequence, the DynaMo model allows the node to be in either of two possible states:

- **Free**, when the set of intra-group and extra-group conditions are satisfied and the node moves according to its standard mobility model;
- **Forced**, when one or more conditions are not met, and the node is moving towards a position compliant with the model requirements.

While in *Free* state, a node can move according to any mobility model.

When in *Forced* state, a node moves towards a position compliant with the set of external and internal conditions. Direction of movement and speed are determined by keeping trace of the previous values of speed and direction, so to avoid violations of upper bounds for speed and rotation rate.

The second part of this section provides a detailed description of the intra-group and extra-group constraints considered in this work.

A. Intra-group constraints

Let us consider N nodes belonging to the same group, referred to in the following as group mates. The DynaMo model requires that each node periodically checks the number of group mates it is connected to, with a period Δu. The set of N_f group mates that the node detects as connected is referred to as its *fellowship*.

The ratio between the cardinality of the fellowship and the total number of group mates is referred to in the following as group factor ρ:

$$\rho = \frac{N_f}{N-1}. \tag{1}$$

The behavior of the node depends on an intra-group condition imposed on ρ. If

$$\rho \geq \rho_{\min}, \tag{2}$$

where the minimum group factor $\rho_{\min}$ is a primary model parameter, the intra-group binding is satisfied. The specific value of $\rho_{\min}$ must be accurately set in order to correctly represent the dynamics of the selected application scenario. If the condition in eq. (2) is not met, the node is compelled to modify its mobility pattern in order to increase its group factor. This is achieved by forcing the node to move at the maximum speed allowed towards the closest group mate not included in its fellowship, while considering at the same time its current situation with respect to the extra-group constraints. Note that running towards the closest group mate not belonging to the fellowship is not the only possible solution when eq. (2) is not satisfied. More sofisticated approaches can be easily introduced in the framework of the DynaMo model, e.g. moving towards the centroid of the positions of its group mates.

The definition of connectivity is a key aspect in the model and DynaMo deals with it in a flexible way, depending on the considered application scenario. In the following connectivity will be determined by means of a distance parameter D_c: a node will consider a group mate as part of its fellowship if the group mate is at physical distance $d \leq D_c$. Note that such a definition of connectivity can be easily related to physical layer radio communication capability by setting D_c equal to the average radio transmission range.

B. Extra-group constraints

The presence and number of extra-group DynaMo constraints depend on the specific scenario. Our choice for the soccer match framework is to define a set of external entities (from the point of view of a Reference Node RN belonging to a certain group) that can be organized in two sub-categories: Fixed External Entities (FEEs) and Running External Entities (REEs). FEEs correspond to specific references in the field: the corners, the goals, the kick-off circle and the two intersections between the boundaries and the halfway line. REEs are nodes belonging to the other groups with respect to RN. Depending on the role of the player embodied by RN and consequently on the nature of its group (defenders, midfielders, forwards) a subset of FEEs and REEs is involved in the definition of the extra-group constraints. As an example if RN is a defender, his external constraints will be represented by a set of proximity thresholds involving the corners, the goal, the midfielders and, in addition, the forwards of the opponent team. Note that the specific values for the thresholds, as well as that of $\rho_{\min}$ for the intra-group constraints, can be varied according to the particular team strategy to be analyzed. This aspect will be carefully taken into account in the future.

III. Physiological data collection

The assumption is made that each player is wearing a BAN that is continuously collecting his physiological data. BAN information packages are routed to a central system that acts as a Physiological Information Data Aggregator (PIDA). The internal configuration of each BAN is in line with the network settings presented in [13] and can for instance rely on a Ultra Wide Band (UWB) physical layer. The propagation of players data towards the PIDA can take place using a wireless transmission protocol of choice, provided that a proper interworking interface is set up between the BANs and the overlay network, such as a BAN coordinator, also acting as a gateway. The performance analysis presented in section V is provided assuming that the PIDA is placed in the proximity of one of the goals.

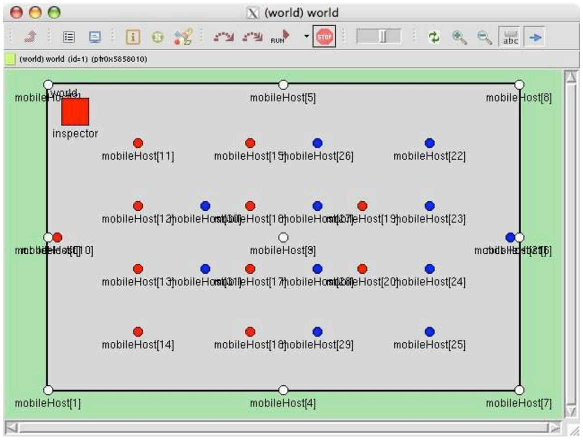

Fig. 1. Initial disposition of players used for simulation of both DynaMo and RPGM models (Red nodes: team 1; blue nodes: team 2; white nodes: fixed anchor points).

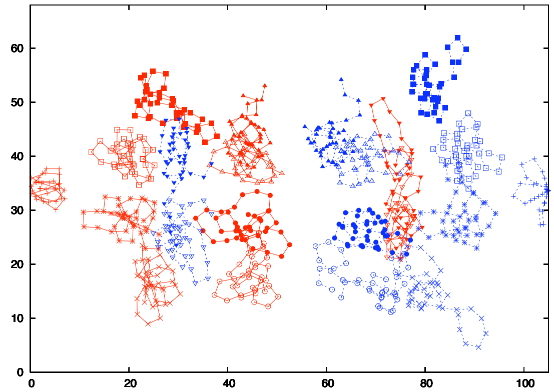

Fig. 2. Example of mobility pattern generated by the DynaMo mobility model after 50 seconds of simulation (Red solid plots: players of team 1; blue dashed plots: players of team 2; different symbols correspond to different players).

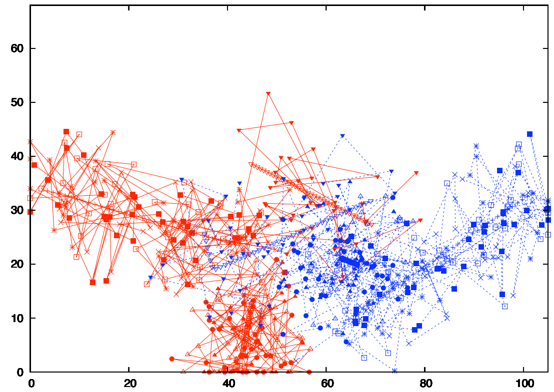

Fig. 3. Example of mobility pattern generated by the RPGM mobility model after 50 seconds of simulation (Red solid plots: players of team 1; blue dashed plots: players of team 2; different symbols correspond to different players).

IV. Mobility Patterns

The DynaMo model aims at reproducing the mobility patterns of players during a footbal match, by taking into account the relationships between players and their role in the team. In this section the mobility patterns resulting from the model are analyzed and compared with those resulting from the RPGM group mobility model [12].

The RPGM model defines a logical reference point for each group, whose movement is followed by all nodes in the group. The path followed by the reference point defines the entire group mobility behavior, including position, speed, direction, acceleration, etc. The group trajectory is thus determined by providing a path for the reference point, any node in the group being randomly placed in the neighborhood of its reference point within a maximum distance d_{max}. An alternative solution for the definition of the reference path is to elect one of the nodes in each group as its leader, and to use its position as the reference point for the other nodes in the group. The latter approach was followed in this work, with the leader of each group moving according to the Random Waypoint model [14]: each leader started moving by randomly selecting destination and speed, and upon reaching the destination it selected a new one as well as a new speed.

Simulations for both DynaMo and RPGM models were executed starting from the topology presented in Figure 1, representing a typical disposition of players at the beginning of a match. Simulations were run with settings presented in Table I, and examples of the resulting patterns for the DynaMo and RPGM models over 50 seconds of simulations are presented in Figures 2 and 3, respectively. Figures highlight that the DynaMo model is able to preserve the relative positions of players while allowing free movement, while the RPGM model leads to a topology that is quite far from to the original one. Note that the patterns of the RPGM model are heavily depending on the trajectories followed by the group leaders; it can be expected that patterns closer to realistic behavior of soccer players during a match can be achieved by assigning ad-hoc patterns to the group leaders. The issue of how to determine such patterns is however not a trivial one.

V. Impact of Mobility on Network Performance

The DynaMo and RPGM mobility models were also compared in terms of their impact on the performance of inter-BAN communications in the application scenario identified in Sections I and III. The performance of the network was evaluated by measuring the end-to-end throughput and the end-to-end delay under the following assumptions: 1) each BAN coordinator was equipped with a low rate Impulse Radio Ultra Wide Band transceiver compliant to the IEEE 802.15.4a standard [15]; 2) the Medium Access Control protocol adopted a Pure Aloha approach; 3) the Ad-hoc On Demand Distance Vector (AODV) protocol was adopted for inter-BAN routing [16]. Simulation settings are presented in Table I.
Results are presented in Figure 4. Both throughput and delay values show that different mobility models can lead to significantly different network performance; in particular when the DynaMo model is selected higher performance compared to the RPGM case is achieved, thanks to the more regular disposition of nodes.

TABLE I

SIMULATION SETTINGS

Parameter	Value(s)
Area	105x68 m^2
Number of terminals	22
Δt	$1\,s$
T	$5\,s$ (DynaMo)
v_{max}	$3\,m/s$
v_{min}	$0.001\,m/s$
Δu	$1s$ (DynaMo)
d_{max}	$30\,m$ (RPGM)
Simulation time	1000 s
Physical layer settings	Impulse Radio, Bandwidth= 500 MHz, Transm. rate = 966 kb/s, Transm. power = 36.5 μW
Traffic model	CBR @ 20 kb/s
Average conn. duration	12.5 s
Average conn. request interval	250 s
Channel model	IEEE 802.15.4a outdoor [17]

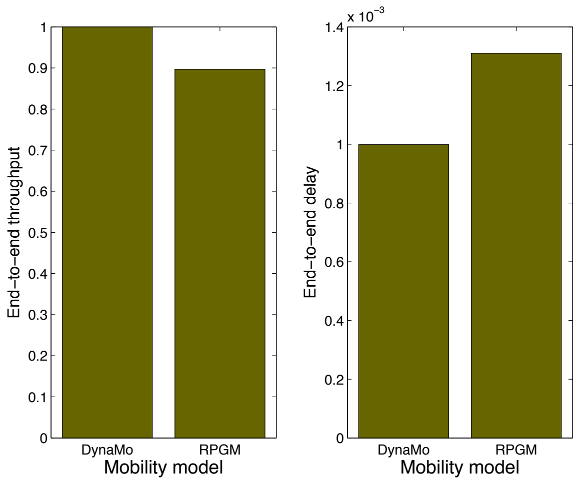

Fig. 4. Average end-to-end throughput and delay measured in inter-BAN communications when adopting DynaMo vs. RPGM mobility models.

VI. CONCLUSION

In this paper a novel mobility model, named DynaMo, has been proposed. DynaMo is capable of modeling both individual movement patterns and group mobility behaviors. DynaMo was used to model mobility of players during a soccer match, and mobility patterns show that the new model is able to preserve the relative positions of players while allowing free movement, while this is not true for preexisting mobility models, such as RPGM. The impact of DynaMo vs. RPGM models on network was then evaluated in an application scenario focusing on the collection of the players biomedical data, where each player wears a BAN that acquires physiological data to be aggregated by a central information device placed in the proximity of one of the goals. Network performance evaluation in terms of throughput and delay shows that different mobility models lead to significantly different network performance, and confirm the need for accurate mobility models in the analysis of wireless mobile networks.

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