Reducing Energy Consumption in Human-centric Wireless Sensor Networks

Roc Meseguer[1], Carlos Molina[2], Sergio F. Ochoa[3], Rodrigo Santos[4]

[1]Departament of Computer Architecture, Universitat Politècnica de Catalunya, Barcelona, Spain
meseguer@ac.upc.edu

[2]Department of Computer Engineering, Universitat Rovira i Virgili, Tarragona, Spain
carlos.molina@urv.net

[3]Computer Science Department, Universidad de Chile, Santiago, Chile
sochoa@dcc.uchile.cl

[4]Department of Electrical Engineering, Universidad Nacional del Sur – CONICET, Bahia Blanca, Argentina
ierms@criba.edu.ar

***Abstract*— Energy consumption is a main research issue in wireless sensor networks; and particularly in those where nodes collaborate to reach a goal. This article explores the energy consumption in mobile devices participating in a human-based wireless sensor network. Specifically, the paper proposes the use of a message predictor to help detect and reduce the number of unnecessary control packets delivered by the nodes as a way to keep updated the network topology. In order to evaluate this proposal, the Optimized Link State Routing protocol was modified to add a message predictor between the routing and the network layers. Eleven simulations were performed using a particular setting. The preliminary results indicate the use of the message predictor can help reduce considerably the nodes energy consumption without affecting the routing capability of the protocol. Although these results are still preliminary, they are highly encouraging.**

Keywords– human-centric wireless sensor network, energy consumption, messages prediction, opportunistic network.

I. INTRODUCTION

Mobile technology plays an important role in the life of many people, and everything indicates that it will become more and more relevant in our lives. Although such a technology is mainly used to provide mobile communication, it can also be used for sensing. For example, a smartphone with a WiFi antenna could act as a sensor able to detect in a certain area, the physical presence of devices belonging to a friend or a relative. Thus, it is possible to sense the presence of people physically close to the user location. This capability allows mobile devices to support users in several scenarios, such as tourism, shopping or entertainment. In fact, these sensing units are useful to facilitate casual meetings between service providers and potential clients.

The sensing capabilities provided by mobile devices are particularly helpful in crowded areas, e.g. a fair, where is not easy that potential clients can identify potential providers of a service. In order to exemplify this point, Fig. 1 shows a job fair where potential job applicants (indicated with a dashed circle) need to identify potential headhunters (indicated with a circle). The edges indicate the compatibility links among them, which should generate a personal contact among them.

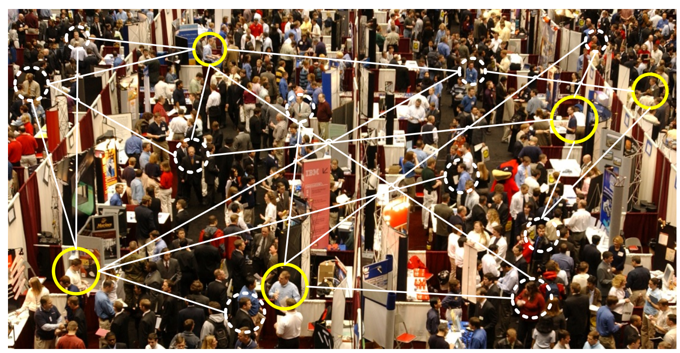

Figure 1. Example of compatibility links between job applicants and headhunters in a job fair

Today, participants in these fair use their skills to try identifying people potentially matching with their job requirements or expectations. Such a matching strategy is clearly inefficient and usually ineffective. Therefore the use of mobile applications acting as sensors can represent a contribution to help connect people in crowed scenarios, like a job fair or a marketplace.

Ochoa and Santos [10] have named this type of networks as Human-centric Wireless Sensor Networks (HWSN). A HWSN has been defined as an opportunistic network (oppnet) that uses the mobile devices' communication capabilities to build a dynamic mesh. These networks, as any other oppnet, are able to route messages from a source to a destination node, without knowing if there is a path between them [11].

The nodes of a HWSN can be *regular sensors* (e.g. GPS), *human-based sensors* (e.g. people using a mobile application) and *information holders* (e.g. passive re-transmitters). However the main actors in these networks are the human-based sensors, which have the capability to send/receive information on-demand to/from other sensors. In case of the scenario shown in Fig. 1, a human-based sensor can be implemented as a software application running in the smartphone of job applicants or headhunters. The application could be used to detect the physical presence of candidates in the area close to a user. Then, using such information the application can trigger a request for a face-to-face meeting or guide the user towards the other user's location.

In a HWSN the human-based sensors participate in the messages routing, therefore the energy consumption of the nodes becomes a critical issue. The power autonomy of these mobile devices indicates the time period in which they will be useful for their respective users.

When a HWSN is deployed in a crowded area, where the offer and demand for personal contact is high, it is easy to realize that the message traffic and the energy consumption will be important in almost every node. If we consider that a smartphone (i.e. the most typical node used in public areas) has low autonomy when using intensively its communication antennas, it is clear that a HWSN should try to optimize its routing protocol in order to reduce the power consumption of the nodes, without affecting the messages delivery. This is particularly the challenge addressed in this article.

Several approaches have been proposed in the literature to reduce the information overhead in mobile ad hoc networks [7, 8], and thus to deal with the problem of energy consumption in mobile devices participating in oppnets. However, none of these proposals use messages prediction as the instrument that allows reaching such a goal, which is particularly the strategy proposed in this study.

In order to evaluate the potential impact that message prediction can produce in the energy consumption of nodes participating in a HWSN, we have modified the Optimized Link State Routing (OLSR) protocol [9], which is one of the most well known proactive protocols for routing messages in oppnets.

Next section describes how the messages prediction in oppnets can help reduce the traffic and energy consumption in nodes of a HWSN. Section III indicates how the messages prediction is addressed in this proposal. Section IV briefly describes the OLSRp routing protocol, which is an adaptation of OLSR that includes messages prediction. Section V describes the simulation setting used to evaluate the proposal. Section VI presents the obtained results. Section VII discusses the related work. Finally, Section VIII presents the conclusions and the future work.

II. PREDICTION IN OPPORTUNISTIC NETWORKS

Prediction is a well-known and crucial technique in computer microarchitecture for achieving high performance and it has been applied successfully for years to several parts of the processor. This technique benefits from the huge amount of redundant computation that presents the program execution in a processor. Typically, if the percentage of predictions is high enough, the overall microprocessor performance is significantly improved at a reasonable hardware cost. In this article the authors hypothesize that the same benefits can be extended to oppnets supporting HWSN. Thus, we could improve the power autonomy of human-based sensors, particularly when they are used in areas with high message traffic.

Prediction can be performed in different ways and it does not necessarily need to rely on the past history. However, a repetitive behavior facilitates the prediction process. Last-value is the simplest prediction approach, which benefits from the repetition of the last value that was observed by a node. If we analyze this repetition (i.e. last received message is equal to the preceding one) in OLSR control messages, we can assure that [5]:

- *The number of nodes does not affect the percentage of repetition*. Given a certain speed of nodes mobility and nodes density, there are no significant differences in terms of repetition when the number of nodes is increased. That means that it can be achieved the same percentage of repetition just by increasing the number of nodes.
- *The percentage of repetition is affected by nodes mobility.* This percentage ranges from 80% to 98% when the speed is 0.1 m/s, from 40% to 80% when the speed is 1 m/s, from 20% to 40% when the speed is 5 m/s and, finally, from 5% to 20% when the speed is 10 m/s.
- *The percentage of repetitions is significant with human walking speeds.* This percentage moves from 40% to 80% depending of the nodes density. The lower density the higher repetitions, and the higher density the lower repetitions.
- *The density of nodes slightly affects the percentage of repetitions.* Given a certain speed of nodes mobility and number of nodes, there are only small differences in terms of repetition between different levels of nodes density.

Based on these observations, we can modify the OLSR routing algorithm to predict the control messages that nodes need to exchange for building an accurate map of the network topology. Thus, the nodes can avoid resending the same information, which it is translated into two important advantages:

- *It reduces energy consumption and CPU processing time* because fewer routing control packets are sent and received. This packet reduction is particularly interesting because the energy consumed by OLSR traffic increases with number of nodes (see Fig. 2). Therefore, we can reduce the number of messages transmitted through the network and thus saving CPU and energy consumption.
- *It reduces network collisions* because the predictor only sends non-redundant routing control information, thus reducing the message traffic. Fig. 3 shows clearly (for different node densities) that the traffic generated by the OLSR protocol grows almost exponentially with the number of nodes. High density means 125 nodes/km^2, medium density means 15 nodes/km^2 and finally, low density means 5 nodes/km^2.

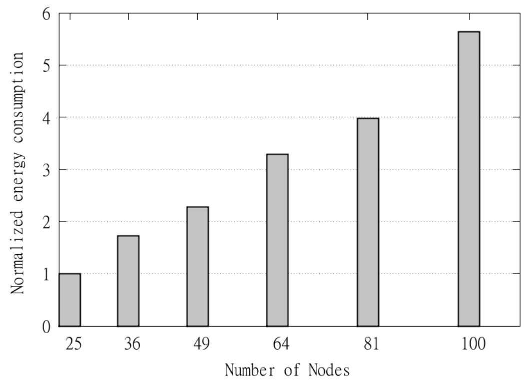

Figure 2. OLSR energy consumption vs. number of nodes

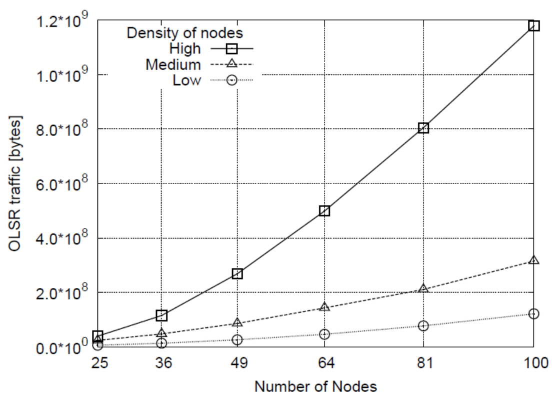

Figure 3. OLSR traffic vs. number of nodes

III. The Prediction Mechanism

In link state routing protocols, nodes periodically disseminate control information to the rest of the network nodes. This information is always injected to the network, even if it is the same as the one sent the last time or if the control information is empty. This clearly produces an unnecessary CPU and energy consumption.

In order to address this issue, we propose to modify the routing protocol to include a component able to predict the next control packet that should be sent or received. Such a predictor is located between network and routing layers (Fig. 4).

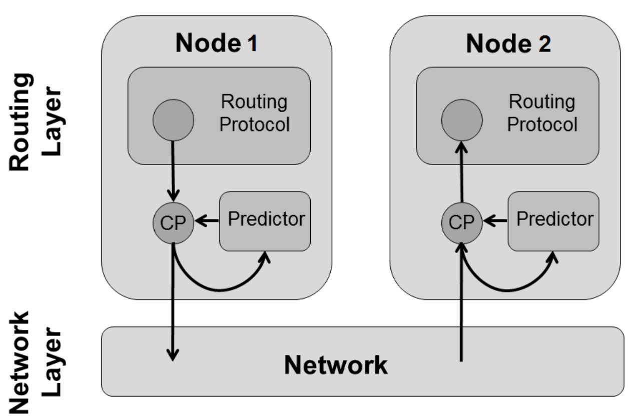

Figure 4. Network architecture including the predictor

A "node 1" periodically generates a control packet that we will name "generated CP". Following the same pace the predictor predicts next control packet as a result of the application of a prediction algorithm. We will name these packets as "predicted CP".

The system will deliver a new control packet to other network nodes as a result of applying a merge algorithm that considers the generated and predicted packets. Moreover, this occurs if both packets (i.e., generated and predicted) do not contain exactly the same control information. After any delivery, the predictor stores the information of the new control packet, which will be used for new predictions.

As shown at the right side of Fig. 4, a "node 2" periodically receives control packets from other nodes, which are considered as "generated CP". At the same pace the predictor determines next control packet that should be received (predicted CP). If no control packet is received through the network, the routing protocol processes the "predicted CP". In other case, the routing protocol processes this new control packet and the predictor stores a copy of it for the next predictions.

In this strategy each node predicts a control packet that is used to generate every new control packet, which eventually will be injected to the network. Moreover, each node predicts all control packets that it should receive from other nodes. This scheme considers one predictor by each node that a packet can be received from.

Prediction and merge algorithms can be almost any. For example, in case of the prediction algorithm we could use "the last control packet injected to the network algorithm", which is similar to last value of the architecture predictor.

IV. OLSR with Prediction

OLSR with prediction (OLSRp) [5] was introduced by the authors as a scalable routing mechanism that focuses on eliminating redundant control information, and thus to reduce the CPU and energy consumption in mobile ad hoc networks. This strategy was defined based on the empirical observation that the probability of receiving a control message containing the same information as the previous one is very high. In fact, it is demonstrated that message repetition is only affected by nodes mobility and it remains almost constant when changes the nodes number or density. Consequently, it can be orthogonally applied to diverse scenarios where these parameters are different.

Basically, this approach places a last-value predictor [6] in every node of an oppnet to prevent them from transmitting duplicated Topology Control (TC) packets throughout the network. It is implemented as a transparent communication layer between the routing and the network layers.

A node with or without OLSRp deals with exactly the same control traffic. The main difference is that the data sources for the OLSR layer are different. When the OLSR is used alone, all the information comes from the WiFi layer, whereas when the OLSRp is used, the information can be provided by both the WiFi and the OLSRp layer. This means that OLSRp does not modify the number of TC messages that are processed, but it reduces the amount of TC messages transmitted through the network. Messages that are not transmitted are predicted by the receiver. In OLSRp the nodes behavior can be summarized as follows:

- A given node executes a prediction when it has a TC message to transmit. Because OLSRp launches a last-value predictor, the result of every prediction is always the last TC message generated by the node.
- Immediately after a prediction is made, OLSRp compares the prediction result with the new TC message generated by the node. If both messages are the same, then the node does not transmit the new TC message. Because the OLSRp protocol runs in every network node and all nodes have the same last-value predictor, every network unit will calculate the same TC message in the same round.
- By making this prediction, each node is able to reuse the same TC information, and thus to prevent the transmission of duplicated messages. The OLSRp protocol is 100% accurate because the prediction results are always inferable (i.e. all nodes expecting a given TC message will always be able to predict the same TC message).
- When OLSRp cannot make a prediction, a new TC message is transmitted. Dealing with the fact that destination nodes may not be properly working, OLSRp uses the reception of the HELLO messages generated periodically by the network nodes, as a topology validation method. Therefore, if a node does not receive a HELLO message, it means that the node is inactive or the network topology has changed. Consequently, the OLSRp will deactivate the predictor and will send the real TC message.

V. EXPERIMENTATION SETTING

In order to understand the effect that the reduction of TC messages has on the energy consumption of the mobile devices (i.e. nodes of a HWSN), we have designed and run several simulations. We use the ns-2 [1] simulator during this validation process because it allows us to model several network scenarios and collect statistics through the generation of PCAP (packet capture) files. Such a simulation tool allows us also to define network topologies, configure wireless network interfaces and set node mobility patterns.

For the simulations, we have considered a physical area of 200m x 200m, which simulates a marketplace. In such a scenario we have considered 25 stationary nodes (e.g. product providers) and 275 mobile nodes (e.g. potential clients). Nodes were randomly deployed in an open area, where there are no walls interfering the WiFi signal used by these devices to support their interactions. In this scenario we did 11 different simulations using both, OLSR and OLSRp.

We have assumed that all nodes are similar, and with technical features equivalent to a smartphone; particularly we have considered the features of the iPhone 4 for stationary and mobile nodes. These devices have an effective communication threshold of 80 meters approximately in open areas. In such a threshold we can expect that the ad hoc communication among devices is stable and the bandwidth of at least 50Kbytes, which is appropriate to support reliable synchronous interactions. Mobile nodes (e.g. potential clients) have a random mobility and a walking speed of 0.7 meters/second, due we are considering that the marketplace has a regular people density.

We have also considered that the WiFi channel has a constant propagation delay and it follows a Friis propagation loss model. The routing protocols were set to deliver HELLO messages every 2 seconds and TC messages every 3 seconds. We also generated a data traffic (i.e. messages with content generated by the mobile application) that consists of several UDP packets transmitted every second. We also set stationary nodes to act as Echo servers and the mobile nodes to act as Echo clients. Every simulation lasted 200 seconds.

VI. OBTAINED RESULTS

Fig. 5 shows a histogram of the energy consumption versus number of network nodes. The results indicate that nodes using OLSRp consume between 0.3 to 1 Joules during the simulation period, and those using OLSR consume between 0.4 and 2.3 Joules. Therefore we could hypothesize that the use of message prediction could be helping to reduce the energy consumption of the nodes. Comparing the energy use for OLSR and OLSRp we can see that there are statistically significant differences between Means determined by T-test (unpaired samples and unequal variances), when $r = 9.4E\text{-}36 < 0.05$.

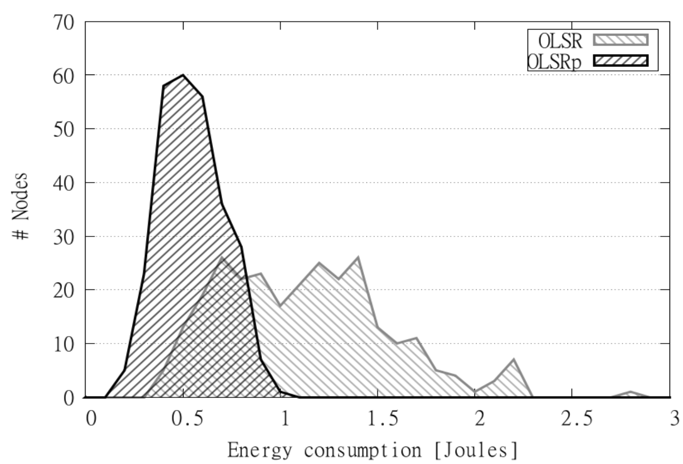

Figure 5. Histogram of energy consumption by number of network nodes

Fig. 6 shows the evolution of the energy consumption according to the nodes degree. The results indicate that the energy consumption grows with the nodes degree. This is an expected result since each node will be connected to a more important number of nodes, and therefore each one will have to route extra traffic that increase the energy consumption. Although this behavior is present when using both protocols, the participation of the predictor helps reduce the slope of the energy consumption. This means that OLSRp improves the performance of the HWSN (from an energy consumption point of view), when they are used in areas with high density of human-based sensors.

Fig. 6 also shows that the dispersion of the energy consumption is considerably minor when using OLSRp. This helps nodes to manage energy consumption more efficiently due they are able to accurately estimate their future consumption as members of a HWSN.

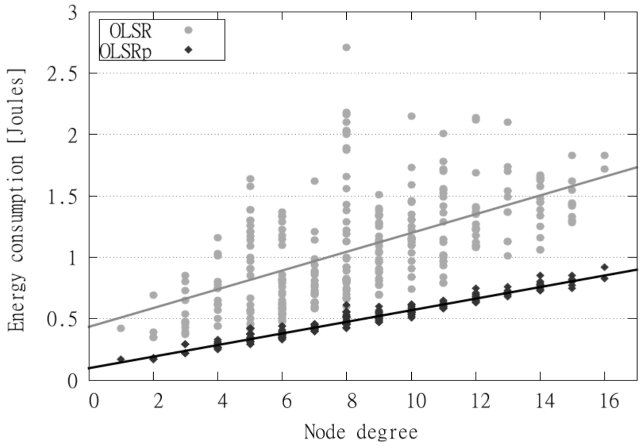

Figure 6. Relationship between node degree and energy consumption

Fig. 7 shows the average number of routing messages by network node, considering just HELLO and Topology Control (TC) messages. It also indicates the maximum, average and minimum values for each message type, considering the 11 simulations.

The results show that the energy consumption reduction is produced by the reduction of the TC messages required to keep updated the network topology. In case of crowded areas, the walking speed of mobile users is low and consequently the network topology will change slowly. Therefore the use of OLSRp will be highly convenient to reduce the transmission of TC packets and thus to increase the nodes autonomy in terms of energy.

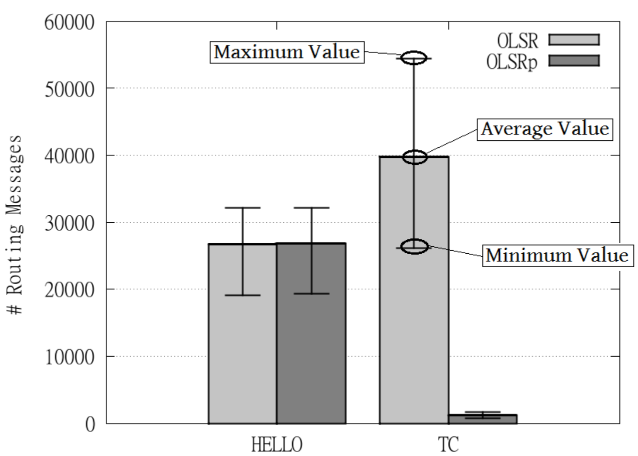

Figure 7. Comparison of average routing messages, considering just HELLO and TC messages

Although the simulation outcomes show that OLSRp reduces the nodes energy consumption, it is also important to verify that such a reduction does not affect negatively the nodes capability to route messages. Fig. 8 shows the maximum, minimum and average percentage of traffic messages generated by ping and multicast messages.

In case of the ping message traffic, it has been generated by randomly coupling the network nodes. Every node in a couple sends ping messages to its coupled node. A total number of 2123 ping messages were delivered in each simulation period.

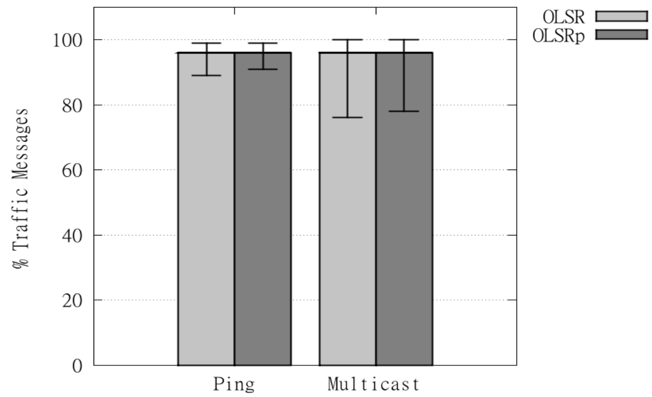

Figure 8. Comparative traffic produced by ping and multicast messages

The comparative ping traffic indicates the percentage of messages correctly received by the destination nodes is similar in both protocols, and also in both cases there was packet loss. However, when using OLSRp the variance of the message arrival rate was smaller than the rate obtained when using OLSR. The same result was observed after processing the traffic produced by multicast messages.

In case of the multicast messages simulation scenario, we used five nodes (randomly chosen) to send multicast messages to the rest of the network nodes. The transmitters sent UDP packets with a size that varies randomly between 10 to 1000 bytes. The nodes data transfer rate was set to 5 Kb/s. Fig. 9 shows the detailed values obtained in the eleven simulations, where we can see that in some scenarios the messages arrival rate reached 100%.

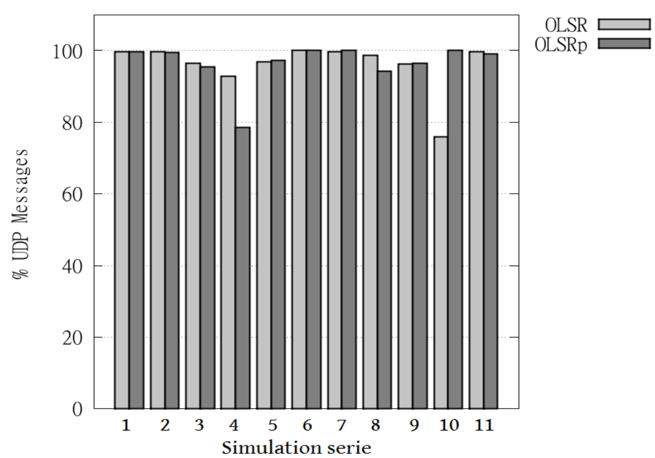

Figure 9. Detailed results of UDP traffic for the eleven simulations

The preliminary analysis of the simulation results indicates that both protocols seem to be equivalent in term of data transfer capability. This would means that the reduction of TC packets generated by the predictor does not affect negatively the routing capability of this protocol. This was the second hypothesis that this study intends to validate.

VII. Related Work

Concerning energy consumption in WSN and oppnets, there are also several interesting proposals, but most of them are not particularly suitable to be applied to HWSN. Le et al. [12] propose a new MAC technique for event-driven wireless sensor network that creates a hierarchical topology, where every node synchronizes with its neighbors to avoid resending the same information. In this way, if a node receives the same information that was sent to the same destination, it will remove this message as it assumes that it has already been sent by one of its neighbors.

Ye et al. [13] propose a robust energy-conserving protocol applied to a very large number of small sensors with short battery lifetime. The protocol deals with geometric information to derive redundancy and thus it allows redundant nodes to be turned off. Similar strategy has been used by [14] in sensor networks and by [15] and [16] in wireless ad hoc networks.

Maleki et al. [2] proposed the Lifetime Prediction Routing protocol where each node tries to estimate its battery lifetime on the basis of its past activity. Hence, it is possible to increase the overall network lifetime by finding better routing solutions that take into account these predictions. The Kinetic Multipoint Relaying protocol [3] focuses on predicting mobility in order to improve routing. This approach selects relay nodes on the basis of the current relay configuration and the future network topology prediction. The Mobile Gambler's Ruin algorithm [4] also applies mobility prediction. This predictive algorithm is developed under a cooperative scenario to identify nodes that are more likely to disconnect in the near future. Therefore, this prediction allows the coordination layer to reschedule the work among nodes in advance.

VIII. Conclusions and Future Work

Energy consumption is a hot research topic in many areas including WSN. This article explores the use of a control message predictor as an instrument able to detect and avoid the delivery of unnecessary control packets in human-based wireless sensor networks. By reducing the message delivery the authors intend to reduce the nodes energy consumption without affecting the routing capability of the network.

In order to validate this hypothesis the authors modified the OLSR protocol to include it prediction capability. The resulting protocol named OLSRp was compared with the original one using eleven simulations. The obtained results show that the use of prediction effectively helps reduce the delivery of TC messages and consequently reduce the energy consumption of mobile devices participating in a HWSN. The results also indicate that the routing capability of the nodes was not negatively affected by the reduction of control messages.

Although these results are still preliminary, they are highly encouraging. Due the use of a message predictor to reduce the energy consumption is independent of the routing protocol used in the HWSN, such a proposal can be easily reused in several other routing protocols for oppnets or WSN.

The next steps in this initiative consider the evaluation of OLSRp in simulated and also in real scenarios, as a way to determine its limits and potential impact. After that we will explore the use of predictors in other routing protocols for oppnets.

Acknowledgments

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