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Review Paper

Cooperative Routing Protocols in Wireless Body Area Networks (WBAN): A Survey

Reza Jafari [1,2,*]
Mehdi Effatparvar [1]

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Abstract
Wireless Body Area Network (WBAN) is composed from the embedded sensors on the body that monitors the vital signs of the body are certain organs. Sensors collect data on the different parts of the body and send them to the sink. In the recent years, significant researches are done for reliable, secure and efficient communications of sensors to transfer collected data from sensors to the sink. Reducing of network lifetime is one of the most important criteria's in WBANs and most of the presented articles in the last years, are focused on providing cooperative routing protocols to achieve minimum energy consumption and longer network lifetime. On the other hand, Packet Reception Ratio (PRR) is another metric has been considered in WBANs' routing protocols to have higher rate of successfully received packets in the sink. We try to list and present some of the recent articles that provide cooperative routing protocols that attempt to reduce network lifetime and PRR.

Keywords: WBAN, Cooperative, Lifetime, PRR.

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1 Department of Computer engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran
2 Department of Computer engineering, Ardabil Science and Research Branch, Islamic Azad University, Ardabil, Iran
* Corresponding author: rz_jafari@yahoo.com

1. Introduction

WBAN is one of the modern technologies that is used to monitoring the patients' status inside or outside the hospital and monitoring athletes' activities, military applications and multimedia in recent years [1, 2]. WBANs consist of the smart, small-size and low consumption sensors and a sink that are usually embedded into clothing, on the body or under the skin [3, 4]. These sensors collect data on the different parts of the body and send them to the sink, for sending other networks or devices such as mobile phones, PDA, and tablets to identify and administrate of the collected data.

Because dimensions of WBANs' sensors are small, batteries of these sensors provide the limited energy. Given that some of the sensors may be embedded within the body or skin, the used batteries aren't rechargeable or replaceable. Continuous data sensing and transmission, and greater distance between communicating nodes may cause more energy consumption.

Therefore, it is essential that in WBAN various fields including routing of the sent packets in these networks, researches on the issue of energy consumption and lifetime of the network be given priority. The received packets from the sensors in sink is a metric that should always be considered and is usually evaluated the network's performance by it.

The IEEE 802.15 Task Group 6 is working to develop a low power and low frequency short range communication standard protocol for WBAN, to optimize the internal and external communications of network and communicate with other devices as possible as [5].

The topology of star is the easiest method for routing of the sensors' sent packets to achieve to the sink. In this way, sensors are communicated with sink directly and their communication model is Single-Hop. This method is the least efficient and the sensors are wasting energy. However, these methods provide lower latency for the sent packets; its cause is the direct communication of sensors with sink.

On the other hand, Multi-Hop communication method uses sensors as dual and it uses the sensors which are at route the transmitter of data packets and sink as forwarder, to get benefit the potential of sensors for energy management and reducing of successfully received packets by sink. In this method the delay of sending the packets is from their disadvantages [6].

Relays can be used to collect data from the sensors and send them to sink in WBAN to reduce the network lifetime and so to increase the reliability [5, 6]. In fact, relays play a very important role in reducing the energy consumption in WBAN that their advantages include to protect the body tissues from radiation waves, but use of the relay increases the number of network nodes that complicate the routing of packets and reduce the cost of network.

One of the most important challenges in WBANs is routing of sent packets from different sensors to sink. Like other networks, WBAN involves problems such as packet loss, congestion and so on that effect on routing packets and successfully receiving in destination. Also regarding to the limited power of WBAN's sensors, if do not manage to send packets in network properly, sensors have to retransmit packets and this leads to consume extra energy or in other word to waste the energy.

Presented routing protocols in WBANs usually are composed from Single-Hop and Multi-Hop methods. In some cases, sensors have to send their collected data to sink directly and often they use Multi-Hop method.

In the cooperative routing protocols that are based on Multi-Hop communication method, sensors or relays which are located in the communication path between transmitter and sink, operate as forwarder. They receive the sent packets from sender sensor and retransmit packets to sink so that energy consumption will be reduced and network performance will be increased too. Cooperative routing allows more frequent data gathering, hence data loss is least expected.

Recently, cooperative communication for WBANs has gained much interest due to its ability to mitigate fading through achieving spatial diversity, while offering flexibility in addition to traditional Multiple-Input Multiple-Output (MIMO) communication.

Some of the recent presented articles in WBAN's routing protocols used relays as forwarder and some ones were used other sensors as forwarder of sent packets from packet transmitter.

The paper is organized as follows. In the second section we introduce and discuss some articles that presented cooperative routing protocols. Finally, some conclusions are given in the third section.

2. Cooperative Routing Protocols in WBAN

Wireless Body Area Network (WBAN) is composed from the embedded sensors into clothing, on the body or under the skin that monitors the vital signs of the body's certain organs. Sensors collect data on the different parts of the body and send them to the sink for sending other networks or devices such as mobile phones to identify and administrate of the collected data.

In recent years, different routing protocols have been presented for sending collected data from transmitter to sink. In the presented protocols some criterias and have been considered and some techniques have been made. In WBAN, cooperative communication has gained much attention. In cooperative communication, a sensor node may act as a source, as a relay or as a destination. In fact, network's sensors help each other to transmit collected data to sink.

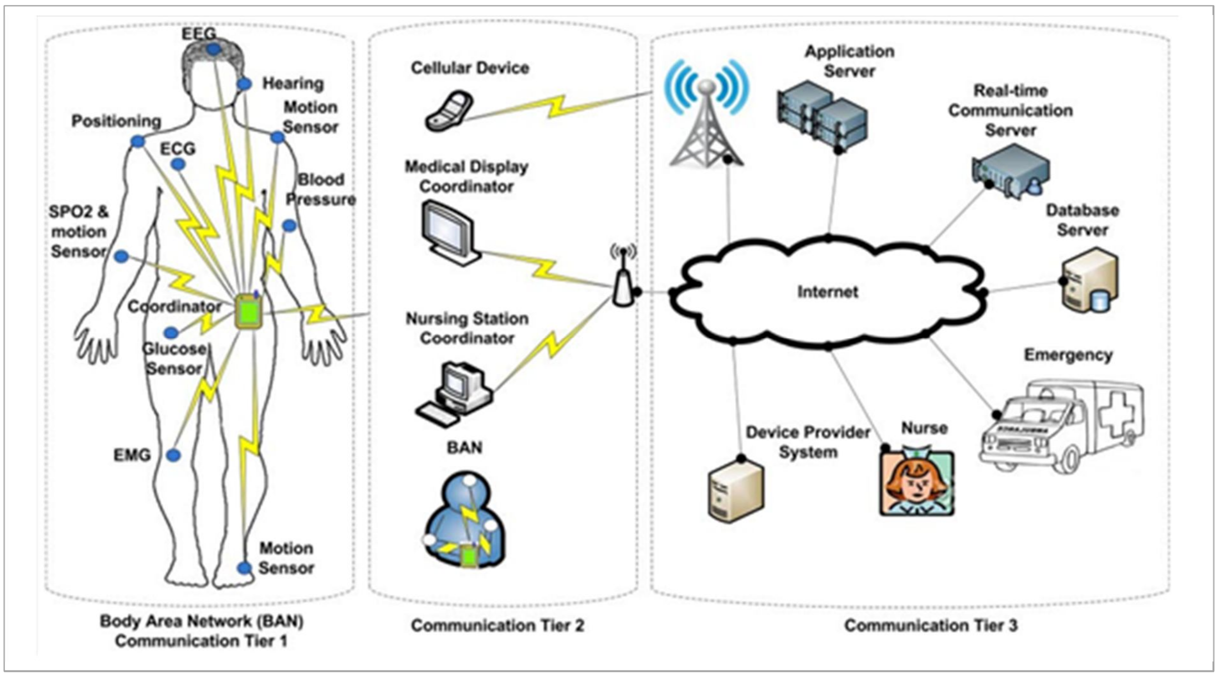

Figure 1. WBAN communication system

Wireless Body Area Network (WBAN) is composed from the embedded sensors into clothing, on the body or under the skin that monitors the vital signs of the body's certain organs. Sensors collect data on the different parts of the body and send them to the sink for sending other networks or devices such as mobile phones to identify and administrate of the collected data.

We categorize WBANs' cooperative routing protocols in two categories. The first category was relay based protocols that uses relays as forwarder of sensors' sent data packet to sink and the second one is the protocols that uses sensors as dual.

2.1. Relay Based Protocols

In this section, we first describe the relay based cooperative protocols and their basic properties. In section 2.1, we discuss the most popular relay based protocols. Finally, the discussed protocols are compared and summarized in section 2.2.

2.1.1. Popular Relay Based Protocols

In the article [7], Jocelyne Elias has provided a model for WBAN which the base of its work is based on relay and he investigates the joint problem of positioning the relay nodes and designing the wireless mesh network that interconnects them. She provides an effective mixed integer linear programming formulation of the WBAN topology design problem, which minimizes the network installation cost while taking accurate account of energetic issues. The considered network in this article is composed of three types of nodes: the biosensors, the sink nodes (which collect and process data from all sensors) and the relays. Biosensors are placed on the body for data collection, and they are connected to sink nodes through a set of relays. Relays form a wireless backbone network which transports the data collected by biosensors to sinks. She assumes that biosensors can share the same radio spectrum in a time division multiple access manner, thus there is no interference between nodes within a single WBAN. She adopts a practical approach to the network design problem, by considering feasible positions where relays can be installed. On the other hand, the biosensors and sinks' positions are usually predetermined and fixed, according to the medical application for which they are deployed. After describing propagation and energy models that their different key issues are: power absorption (specific absorption rate, SAR), human body tissue, fading (small/large scale), path-loss and shadowing, she reviews some recent in-body and on-body channel models. Then she presents an on-body channel model for her work. In this model, when two biosensors (placed on the body) communicate with each other, transmitted signals can arrive at the receiver in three ways: (1) propagation through the body, (2) diffraction around the body and (3) reflections off of nearby scatterers then back at the body. The presented model involves an energy consumption model and to calculate the energy consumption in wireless nodes (sensors and relays), she assumes that the sensing and processing energy are negligible with respect to communication energy. Therefore, the total energy consumption is represented by the total transmission and reception energy of all wireless nodes. Author by presenting EAWD model, has tried to create the changes in the network topology through adding relays and managing how to place them in the network, so that the energy consumption and its implementation cost be reduced. The model's overall objectives include determining the numerical optimum for relays that are placed on the network, and optimal allocation of relays to some of the sensors and optimization of routing in the network. The main purpose of this article is to improve the energy consumption in the network sensors and to increase the network lifetime.

Nadeem Javaid and et.all in the paper [8] presented a routing protocol for in-body sensors in WBAN. The goal of their proposed protocol is to save the energy of in-body sensors in such a way that the network lifetime is increased. They save energy consumption of in-body sensors by reducing the communication distance. So, the idea is to deploy relays on the clothes of patient to ensure reliable network connectivity. The in-body sensors communicate with relays, which act as forwarder of the gathered data to the sink which is responsible for delivering data to the end station. Thus, minimization of communication distance results in extended network lifetime. Moreover, any dynamic change in the position of patient does not affect the protocol operation because the distance of sensors to their respective relays remains the same. They use deterministic approach; in-body sensors are deployed according to the information they are capturing. The communication flow as per their proposed protocol is as follows:

- Sink checks the energy of an in-body sensor. If the sensor is found dead, sink checks for another sensor and continues till an alive one is found.
- If the sensor is found alive, sink proceeds by checking the distance of the sensor with each relay.
- After calculating all the distances for a single sensor, sink selects the nearest relay.
- Sink assigns time division multiple access (TDMA) slots to the sensor and its respective relay.
- Sensor transmits the data during its allocated time slot.
- Relay receives the transmitted data, and forwards it to the sink during the allocated time slot.

- This process continues till the death of all sensors

They also save the energy of in-body sensors in terms of data processing such that none of the two in-body sensors directly communicate with each other. Moreover, they use a linear programming based mathematical approach for network lifetime maximization and E2ED minimization modeling.

Tauqir et.al in a paper [9] presented a relaying protocol named, DARE to monitor patients in multi-hop WBANs. Proposed protocol is based on inspecting a hospital ward with dimensions of 40 ft2 × 20 ft2, under five different scenarios in which, the patients different body organs are monitored to detect any ambiguity in its normal functioning. The ward consists of eight beds where, each patient comprises of seven body sensors placed on different positions and one relay node, on the chest. The topology is kept same throughout the entire ward. This makes a total of fifty six body sensors and eight relays. A node of main sensor is also attached on bed in one of the scenarios to reduce the energy consumption. The main sensor is assumed to have either unlimited or at least very high energy resources as compared to other sensor types. The sink is considered to have unlimited energy resources which then, ultimately transmits the final form of information to the external network. Proposed protocol also supports the monitoring of multiple data types. The sensors measure ailment, either by continuously monitoring the data i.e. on the basis of time-driven events or whenever, a specific threshold level is reached i.e. on an event-driven basis, beneficial for pursuing critical monitoring. The protocol monitors all the eight patients, one by one. In each patient, the body sensor conveys information to a corresponding relay in range, having higher energy resources which, then transmits the received information to the final destination node which, can either be a sink, depending upon the particular scenario. Then they provide an algorithm that communication flow is happen by it. In this paper, five scenarios were considered and in each scenario, the placement of sensors is kept fixed while, the sink node is either made mobile or static. Also the authors provide a radio model in network. For performance evaluation, number of remaining alive nodes during network activity and residual energy, were considered as performance metrics.

2.1.2. Summary of Relay Based Protocols

Table 1 provides the summary of main properties of investigated relay based cooperative routing protocols.

Table 1. Popular relay based protocols and their properties.

Protocol	Main Idea	Advantage	Disadvantage
J. Elias [7]	Determining of the optimal number and placement of relays, the optimal assignment of sensors to relays and the optimal traffic routing.	-Decreases number and installation cost of relays as well as traffic demands. -Determines the optimum in a very short computation time.	-Link quality and path-loss wasn't considered.
N. Javaid et.al [8]	Using a linear programming based mathematical approach for network lifetime maximization and E2ED minimization modeling.	-Deploys relays on the patients' clothes to decrease distances. -All in-body sensors directly communicate with the relays	-Network cost wasn't considered. -Link quality and path-loss wasn't considered. -Less attention to reliability.
A. Tauqir et.al [9]	Implementing in hospital, determining a threshold for every sensor, considering multiple scenarios and a special radio model	-Can be used in hospital. -Patient isn't required to make frequent visits to the hospital.	-Network cost wasn't considered. -Link quality and path-loss wasn't considered. -Less attention to reliability.

2.2. Dual-Purpose Sensor Based Protocols

In this section, we first describe the dual purpose sensor based cooperative protocols and their basic properties. In section 3.1, we discuss the most popular dual purpose sensor based protocols. Finally, the discussed protocols are compared and summarized in Section 3.2.

2.2.1. Popular Dual Purpose Sensor Based Protocols

In the routing protocol which is known as iM-SIMPLE has been presented by N. Javaid et.al in the paper [10] and is an extension of their previous work as SIMPLE protocol [11], besides network lifetime prolongation, they also focus on achieving high throughput. In this protocol all sensors can act as a forwarder for other sensors. They introduce a cost function for the selection of forwarder sensor. The proposed cost function takes two parameters into consideration; sensor node's residual energy and its relative communication distance. The sensor node with minimum distance and maximum residual energy has more chances to be selected as forwarder node. Sensor nodes use direct communication if the residual energy of nodes falls below a certain threshold energy level. In the presented model, all sensor nodes have equal initial power and computation capabilities. They use the first order radio model proposed in [12], mainly due to two reasons: simplicity in implementation and the degree of closeness to their work. The energy costs for transmission, reception, aggregation and amplification of data are calculated based on presented model. Their protocol acts in the following phases: initialization phase, computation of cost function for the selection of forwarder node phase, and scheduling and data transmission phase. In the initialization phase, sink broadcast a short information packet which contains the location of the sink on the body. After receiving the control packet, each sensor broadcasts an information packet which contains their status. In the computation of cost function for the selection of forwarder node phase, to balance energy consumption among sensors and to trim down energy consumption of network, presented protocol elects new forwarder in each round. And finally in the scheduling and data transmission phase, forwarders assign a Time Division Multiple Access (TDMA) based time slots to its transmitter sensors that enforces sensors to transmit their sensed data to forwarder node in its own scheduled time slot. To save energy in transmitter sensor, when a node has no data to send, it switches to idle mode and nodes wake up only at its transmission time. Also in this article, a model is provided for energy consumption that calculates consumed energy in both transmitter and forwarder sensors. Another provided model is for throughput that its objective is to increase successful packet reception at the sink. Their metrics for evaluation of presented protocol are: the time span of network operation before the death of first node (stability period), Time span from start of the network till the death of all nodes (network lifetime), Average total remaining energy of the network after each round (residual energy), total number of successfully received packets at the sink (throughput), and reduction in power level (path-loss).

Ahmed and his colleagues have offered a protocol for routing of data packets as CO-LAEEBA in the paper [13]. Their presented protocol is an extension of their previous work as LAEEBA protocol [14]. They have classified network sensors in normal and advanced sensors. Advanced sensors receive the data packets from transmitter sensors (normal sensors) in addition to its inherent duty and to transfer sink. Normal sensors to select a packet forwarder calculates the cost function for advanced sensors by informing of the status of them. Provided cost function attempts to select a forwarder that its basis is the close distance from sink and the sufficient remaining energy. The authors have also provided different models for Single-Hop, Multi-Hop and mobile sensors in path-loss to raise packet reception ratio in sink. In this protocol, because advanced sensors act as data forwarder of normal sensors to sink, the most of network's load is on them and accordingly they require more energy, therefore the intended initial energy for advanced sensors is about threefold the initial energy of normal sensors. Also according to the advanced sensors, in addition to their data packets, must to send data packets of normal sensors to sink, the capacity of data transmission between the advanced sensors and sink is more than the capacity of data transmission of the normal sensors. A mathematical model is also presented in this paper which is based on a linear three-node arrangement in which Amplify-and-Forward (AF) technique is employed at the relay and FRC is utilized at sink. Channel impairments which are considered in this study are shadowing or slow-fading, path-loss, cumulative noise effects, etc. The authors provide three different model for energy consumption in Single-Hop, Multi-Hop and in the case of Multi-Hop scheme exploits a feedback channel from the destination so that the relay retransmits only if the destination could not receive the message correctly. Their protocol acts in the following phases: initialization phase, routing and co-operation phase, relay selection for cooperation, energy consumption phase, and path-loss selection phase. In the initialization phase three different types of tasks are performed: each sensor is informed with its neighbors, the location of sink on the body is identified and all the possible routes to sink are also evaluated and finally each node broadcast an information packet which contains their status. In the routing and co-operation phase by considering shadowing and path-loss, they present a model for transferring signal between sensors. In the relay selection phase, each sensor in each round selects one of the advanced sensors as forwarder of their packets through a cost function. In the energy consumption phase they calculate consumed energy in single-hop and multi-hop communication modes through presented different models. And finally in the path-loss selection phase, sensors will follow different presented path-loss model based on their status (static or mobile). The simulation results of the article are evaluated with metrics such as the number of the received packets in sink, residual energy of sensors over the network lifetime, network's stability period and path-loss.

Liang and et.al in a paper [15] proposed a tree-based energy-efficient routing scheme that try to achieve a tradeoff between transmission performance and energy consumption. In their proposed power adaptation algorithm, transmission powers are adaptively selected to ensure that sensors transmit packets with just sufficient power. They adopt discrete power levels in their design. The energy of sensor nodes is consumed mainly for two tasks: sensing and communication. As the energy consumption for sensing and packet reception is constant for all transmission powers in their system, they only focus on the energy consumed for transmission. Given that wireless link quality usually changes rapidly in WBANs and sending data with a fixed transmission power may result in either wasted energy or low reliability, an intuitive mechanism is to adjust the power levels of individual sensor nodes according to link quality. Sensors also transmit data to the sink with a high power level by a one-hop or multi-hop path to meet the QoS requirement. However, the energy of those sensors involved in the routing could be depleted rapidly. It is wise to balance the traffic load of all sensor nodes to improve the overall network lifetime. Therefore, they consider not only the total power consumption of the network but also the balance of power consumption at individual nodes. Their study is based on the Collection Tree Protocol (CTP) [16] which is widely regarded as a reference protocol for performing data collection in wireless sensor networks. The basic idea of CTP is to build one or more collection trees, each of which is rooted at a sink. Sensor nodes in a tree use stop-and-wait ARQ with a maximum of M (configurable) retransmissions. Each node not only sends its own data but also forwards data for other nodes. In the case of CTP, a metric called ETX (expected transmissions) is employed to indicate the link quality between a node and its potential parent. For a source node, the path ETX is the sum of the path ETX of its parent and the link ETX between the source node and the parent. Path ETX is calculated based on the successful delivery ratio of routing messages (beacons) and data packets. Similarly, in this paper, they use eETX (energy-aware ETX) to measure transmission quality and regard it as the transmission cost. The smaller the link eETX is, the better the transmission quality is. In order to adapt to the rapid variability of channel condition and balance the energy consumption, they jointly consider adaptive power control and routing in multi-hop WBANs and develop a scheme they refer to as EERS. They augment the scheme a number of supporting mechanisms. EERS includes three functional modules, namely route selection, link quality estimation and data forwarding modules. In order to further improve the performance of EERS, they design a number of supporting mechanisms to solve the problems that are usually encountered in WBANs. These mechanisms are embedded in EERS and are triggered by specific cases. Specifically, Mechanism 1 (eETX-based fast link adaptation mechanism) is designed for fast adaptation to the channel conditions. Mechanism 2 (route repair mechanism) can recover the sensor’s transmission path when the route is broken due to a deteriorated link. Mechanism 3 (resilient smoothing mechanism) flexibly configures the impact of current and previous link qualities for routing. Mechanism 4 (power level switching mechanism) alleviates the oscillation of transmission powers when the link quality is unstable. Mechanism 5 (traffic load balancing mechanism) distributes the traffic load among different relay nodes, and thus helps avoid the early energy depletion of specific nodes. For performance evaluation, they were considered following performance metrics:

- Packet reception ratio (PRR): was defined as the ratio of the number of packets successfully received by the sink over the total number of packets transmitted by originating sensors.
- Average hop count (AHC): was defined as the average number of hops that a packet traverses from a sensor node to the sink.
- Collection delay: was defined as the average delay for transmitting a packet correctly.
- Average number of transmissions per packet (ANTP): was defined as the average number of transmissions before a packet can be successfully received by the sink.

- Energy consumption per packet (ECPP): was defined as the total amount of energy consumed by the network to transmit a data packet from a sensor node to the sink.
- Energy consumption per hop (ECPH): was defined as the average amount of energy consumed per hop to transmit a data packet from the sensor node to the sink.
- Overhead and complexity: they defined the overhead as the number of beacons transmitted by all sensors during an experiment.

2.2.2. Summary of Dual-Purpose Sensor Based Protocols

Table 2 provides the summary of main properties of investigated dual-purpose sensor based cooperative routing protocols.

Table 2. Popular dual-purpose sensor based protocols and their properties.

Protocol	Main Idea	Advantage	Disadvantage
N. Javaid et.al [10]	-Using of all sensors as forwarder and providing an exact cost function. -Formulating linear programming based model.	Considering parent-child approach for sensors' relation.	Less attention to link quality and path-loss.
S. Ahmed et.al [13]	classifying network sensors in normal and advanced sensors and providing an exact cost function.	Providing separate models for radio, energy consumption, path-loss.	Limited number of forwarders was used.
L. Liang et.al [15]	Using Collection Tree Protocol (CTP) for routing of packets	-Providing a low overhead scheme. -Determining several criterias for evaluating their protocol.	Various scenarios and different types of data packets was not considered.

6. Conclusion

In this paper, we categorized WBANs' cooperative routing protocols in two categories and then reviewed and compared the most popular protocols for each category.

The first category was relay based protocols that uses relays as forwarder of sensors' sent data packet to sink. Using of relays despite of complicating of network and increasing expense, leads to decrease energy consumption in sensors and so increase reliability. However, relays usually have replaceable batteries and this case helps to manage network's energy.

The second category was the protocols that uses sensors as dual. Sensors in spite of their basic duty is the sensing of vital signs of body's certain organs, act as forwarder of sent packets of sender sensors. In fact, by this case, has been used the maximum potentialities of sensors and has been prevented from increasing network complicity and increasing network expense. However, by considering the limitations of sensors' energy and not to be replaceable of batteries, it is necessaries that the energy consumption must be regarded in the presented protocols in future.

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