An Adaptive Energy-Saving Routing Algorithm for Mobile Wireless Sensor Networks

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Abstract—**Wireless sensor nodes are mostly limited in their energy. Therefore, it becomes a challenge to extend sensor nodes' life while maintaining the network overall performance. Mobility of the network sensor nodes may accelerate energy depletion and increase the need for effective energy-conserving WSN routing protocols. In this paper, we present a novel energy-saving routing scheme for mobile WSN. Our proposed routing algorithm adapts dynamically to network node's energy-level. For data transport to the network base-station (network sink), it selects only nodes that balance the mobile WSN energy saving distribution. Simulation experiment was conducted to obtain relationships between various algorithm performance measures and network parameters such as: network number of sensors, sensors' message memory/buffer size, message arrival rate, number of duplicates allowed, and transmission/reception distance. The results suggest that the proposed MSN routing algorithm gives around 10% gain of throughput, reduces message duplicates by eight times, eliminates congestion to 0% in average, and increases nodes' life, e.g., First Node to Die (FND), by twofold with a non-significant increase of message delay and jitter.**

Keywords—energy efficiency; Mobile Wireless Sensor Networks Routing; MSN Data Transport Energy Saving Technique

I. INTRODUCTION

Wireless Sensor Networks (WNSs) have been implemented in many fields [1]. The main functionality of WSNs is to gather any scalar, audio, video or still image information from an area surrounding the sensors and deliver it to a base-station (sink). As wireless sensors are mostly limited in size, weight, as well as in cost, the resources of the sensors are also limited including: energy, processing power, and communication functionality [1,2,3]. Their implementations are also specific to design objectives: applications and deployment environment [1]. Therefore, conserving energy is very much important for prolonging the WSNs' life span. Decision of whether a node participates in disseminating information must be related to the energy level in each sensor node. The energy-efficiency issue is highly affected by the number of nodes participating in the dissemination of information. Higher number of nodes broadcasting the same messages will quickly reduce the overall energy of WSNs. Simple-flooding techniques, for example, has been notably known for creating massive redundant messages broadcasting, and as a result, considered energy inefficient. Therefore, careful considerations must be taken when selecting nodes to participate in WSN message dissemination. Energy saving can be achieved by selecting routing path through nodes with high energy level so that it increases the probability for message delivery to the WSN sinks (base-station).

Unlike static networks, nodes employed in ad-hoc WSNs do not have definite routes that will direct the message efficiently to the sink. Global addressing is impossible and IP-based model will not work in ad-hoc scenarios [4]. Creating efficient routing in mobile sensor networks (MSN) is therefore, more challenging than that in static sensor networks. Thus, our research is to develop an optimal routing algorithm for WSNs. The proposed MSN Adaptive Energy Saving Algorithm (MSN-AESA) is a solution to the energy-saving problem of mobile WSNs. This algorithm is an extension to work done in [5] as it adds mobility dimension to the test bed static WSN network routing.

The organization of this paper is as follows: Section II presents the related works, section III discusses the design of our proposed routing algorithm, and section IV, we show simulation results. Finally, the research contribution are summarized in section V.

II. RESEARCH IN WSN PROTOCOLS

The research in WSN protocols is being attempted for more than a decade. In packet-switching protocol layer view, efficient energy consumption can be applied at any of protocol layers: physical layer, data-link, network layer, transport layer and application layer [1]. Besides that, physical placement and mobility of sensor nodes also affect the overall quality of service (QoS) as well as energy consumed [1,3]. Sparse sensor networks require longer radio coverage, consuming more energy, while dense sensor networks consume less power due to smaller radio transmission coverage but may have performance deterioration due to network message collision, which is highly likely to occur. Thus, network topology, WSN nodes distribution and mobility will certainly influence the selection of protocol used in higher layers.

Research in physical and data-link layers of WSNs includes error detection, correction and error recovery techniques. Fair access of bandwidth is also a crucial issue in this area. Improvements on the available standards are progressing. Instead of using conventional ARQ (IEEE standard), Hybrid ARQ [6] is employed in WSNs. B-MAC [7] and TRAMA [8] are also other low level protocols that are claimed to be more suitable for WNSs compared to a conventional MAC protocol.

In the network layer, efficient routing of packets reduces the overall amount of energy dissipated. Highly redundant packets scattered over the sensor networks ignites higher energy consumption. Therefore, creating energy-efficient routing schemes is necessary to achieve long lasting WSNs. SPIN protocol proposed in [9], claims to reduce energy dissipation by 3.5 compared to simple-flooding scheme. SPIN protocol provides more efficiency with the use of ADV and REQ packets to decide which node will be responsible for receiving a message. Some other protocols are also available. They are, but not limited to: CEERA [5], Directed Diffusion [10, 11] CADR [12], COUGAR [13], ACQUIRE [14], LEACH [15], and PEGASIS [16].

Transport schemes for delivering data also directly impact the energy use. Continuous data delivery needs large energy dissipation compared to even-driven data actions. For transport layer, transport reliability can be achieved by exchanging packet control messages i.e. providing end-to-end or hop-by-hop acknowledgment and packet recovery [1]. Acknowledgments of packet handover are important to eliminate multiple-packet retransmissions that consumes more energy. However, transport protocols are designed to be application independent and to provide variable packet reliability for a broad spectrum of applications. The transport layer protocol performance may therefore have a performance trade-off with energy saving at WSN nodes. Failures of nodes should not block packets going to the sink. Examples of available protocols that consider packet transport reliability include: PORT [17], GARUDA [18], DST [19], PSFQ [20], and ESRT [21].

In the application layer, energy efficiency can be established by involving more local message buffers to receive packets. Every packet received within a specific period of time will be aggregated prior to its forwarding to neighbor nodes. Practically, this will save more energy for transmission. Min-max-average method is one example of data aggregation with duplication suppression [22]. Tracking and monitoring moving objects is another type of WSNs' deployment application. Habitat WSNs is one example of sensor network with moving object tracking and monitoring activity. It can be used for various applications such as: providing information about habitat status day or at night, monitoring animal movements, or detection of sea and ocean pollution. This requires routing protocol suitable for moving nodes as there is no fixed routing path. An example of implemented habitat tracking mobile WSN is ZebraNet [23] which tracks the movement of a collection of Zebras in Kenya. The wireless sensor node is attached to zebra's collar. Such sensors are equipped with four Megabits flash memory working at 900 MHz radio frequency equipped with Geo Positioning System (GPS).

Overall, WSNs' applications, however, are very specific, depending on the type of information that needs to be delivered to the sinks: time sensitivity, reliability, and the continuity of data. Again, a trade-off may occur that impact the energy-saving requirement.

III. MSN-AESA SYSTEM DECISION AND OPERATION

With continuous mobility of network sensor nodes in habitat tracking and other WSN applications, development of efficient energy routing scheme is essential. MSN-AESA addresses such needs of mobile sensor network while allowing long nodes life time. The design of the algorithm and its theory of operation is discussed in what follow:

1. If a node *Ni* receives a new message *Mj*, then *Ni* checks for its energy and its memory. If both resources are available, node *Ni* schedules the message *Mj* for a rebroadcast after time *Tk*. If either the node's energy or node's memory is not available, node *Ni* discards the message *Mj* and records the rejection. *Tk* is set as a function of node and message parameters as to be explained later.
2. During the waiting for rebroadcast, *Ni* listens for other messages to arrive.
3. If message *Mj+1* is received and it is a duplicate message queued in memory (scheduled to be broadcast), node *Ni* checks that message *Mj+1* does not exceed the maximum allowable number of duplicates of *Dj (i.e D ≤ Dj).* If this is satisfied, node *Ni* then reschedules the message *Mj* for a different period *Tk+1.* If not, node *Ni* rejects the message *Mj+1* and records the dropping
4. If an ACK message *AMj* is received from a base-station (BS) during the waiting period, node *Ni* drops the related message *Mj* from its memory buffer.

The waiting time *Tk* itself is a function of the remaining energy level of node *Ri*, number of messages *Mj* buffered (scheduled in the local memory), and number of duplicates heard by the node. Other parameters may also be considered such as priority, distance to source, etc. by scheduling function. Through appropriate setting of scheduling time *Tk*, the algorithm will logically select the best candidate nodes to transmit the received message in terms of remaining node energy, memory occupancy, and number of duplicated messages. Equal scaling factor or weighted scale may be applied to these WSN's parameters (energy level, memory and number of duplicates).

Based on the above, the proposed algorithm allows WSN nodes to cooperate in selection of the best candidate node for message retransmission. In addition, it distributes this task fairly among network nodes.

IV. RESULTS AND PERFORMANCE ANALYSIS

Based on the CEERA design [5], a simulation model was developed to evaluate the performance of our algorithm. The model was built using the NS-2 Network Simulator. Various performance measures such as: throughput, number of retransmission (duplication) of messages, message delay, delay jitter, and congestion level were investigated in this study. Here, we define the congestion level as how many duplicate messages to be received by a node within the message waiting period for rebroadcast (RAD – Random Assessment Delay). In addition, we also measure the time it takes for the first-node to die (FND) and half of the network nodes to die (HND). The performance of MSN-AESA will directly be compared with the simple-flooding scheme.

The simulation time is set to 1500 seconds, and bandwidth is made sufficient for both MSN-AESA and simple-flooding scheme to function. Therefore, performance can be fairly compared. Simulation experiments were conducted by changing one parameter at a time while keeping the others fixed. In the simulation experiment, we considered following input parameter's values:

1. Network density or number of sensor nodes $\{n\}$, varies from 60 to 160 nodes. For our study we set the network density fixed to 100 nodes for experiments requiring a constant/fixed network density.
2. Message arrival rate $\{r\}$ is variable from 0.6 message/minute to 1.6 message/minute. For our study we set $\{r\}$ to 1 message/minute for experiments requiring a constant/fixed rate.
3. Transmission/reception distance (*Dmax*) varies, from 175 meters to 300 meters. In our study it is set to 250 meters for experiments requiring a constant/fixed *Dmax*.
4. Memory/buffer size $\{b\}$ capable of storing new messages. It can store up to 16 messages. In our study it is set to 10 new messages for experiments requiring a constant/fixed buffer size.
5. Maximum duplicates allowed for rescheduling $\{d\}$ is variable from 5 to 30 duplicates. In our study it is set to 20 message for experiments requiring a constant/fixed duplicate threshold.

The experiments conducted generated various graphical performance results. Herewith, we present only few of them that are considered most important. MSN-AESA outperformed the simple-flooding scheme by around 10% more throughput in every simulation experiment with various values of network node number and message arrival rate. This can be achieved, provided that higher values are set for *Dmax,* memory size, and maximum number of duplicates allowed. Fig. 1 shows a comparison of MSN-AESA throughput performance for different network density. The other parameters are set to $r = 1$ message/minute, $Dmax = 250$ meters, $b = 10$ messages, and $d = 20$. It reveals that a high density network decreases both schemes. However, MSN-AESA gives more stability to the throughput.

Fig. 2 depicts an impact of lower transmission/reception range (*Dmax*) which results a lower MSN-AESA throughput. Therefore, to have improved result, *Dmax* must be set around 250 meters or more for the algorithm to achieve that 10% gain. Likewise, maximum duplicates allowed must not be less than 10 messages (see Fig. 3), with each node buffer capacity of at least eight messages (see Fig. 4).

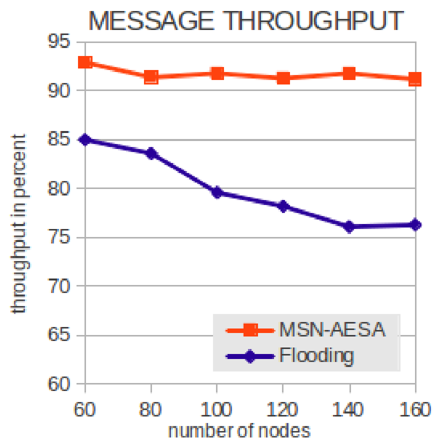

Fig. 1. MSN-AESA comparison to simple-flooding scheme

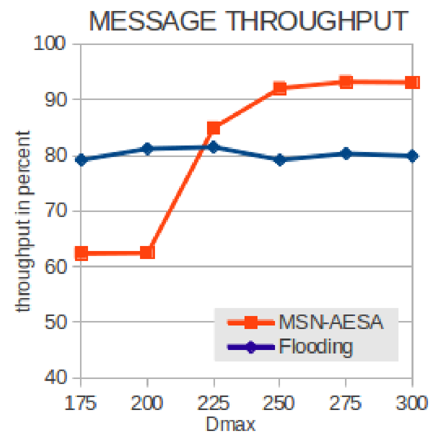

Fig. 2. Impact of Dmax on throughput performance

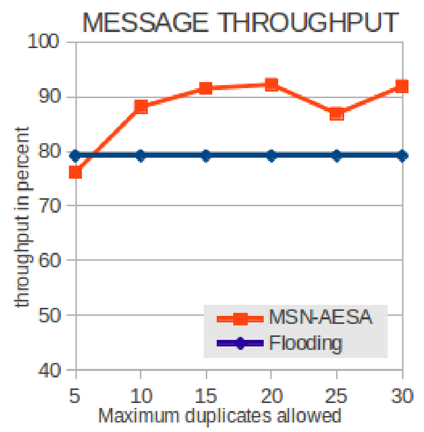

Fig. 3. Throughput performance versus maximum duplicates number.

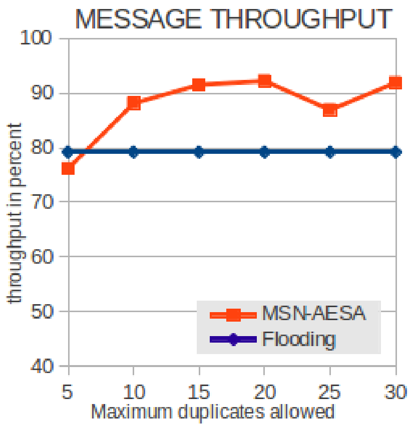

Fig. 4. Throughput vs node's memory size.

For delay and jitter performance measures, dense network noticeably increases message delay as well as message jitter for the simple-flooding scheme. It does not, however, significantly affect MSN-AESA's message delay as shown in Fig. 5.

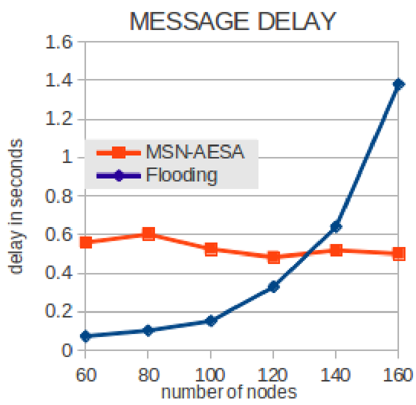

Fig. 5. Delay performance for MSN-AESA

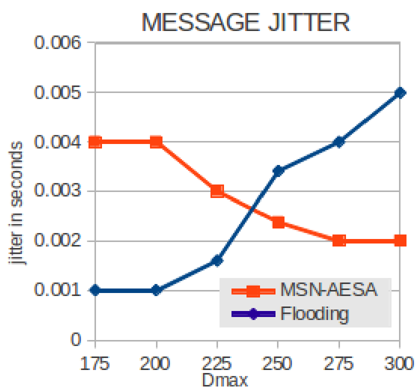

Fig. 6. Jitter performance for MSN-AESA compared to simple-flooding

MSN-AESA also has a constant jitter in such a network. It is also shown that lower *Dmax* contributes to higher delay and jitter. Fig. 6 shows comparison of delay jitter for simple-flooding and MSN-AESA schemes. For message duplicates, MSN-AESA reduces duplicates by eight times compared to that of simple-flooding. In MSN-AESA, duplicates increases with the increase of *Dmax* and memory size as shown in Fig. 7.

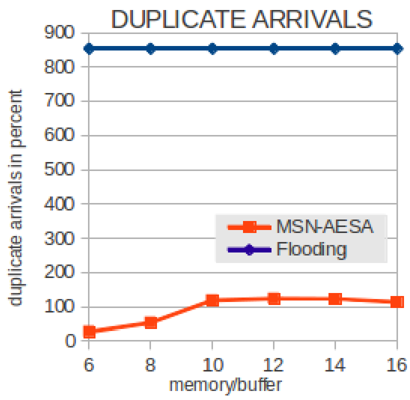

Fig. 7. Jitter performance for MSN-AESA compared to simple-flooding

Our study also showed that congestion level is reduced ideally by MSN-AESA to around 0%. In simple-flooding, congestion is highly dependent on network density, message arrival, and *Dmax*. Fig. 8 shows the congestion level vs. the number of network nodes. The congestion level is set when there are 20 or more duplicates for a given message are received at any node.

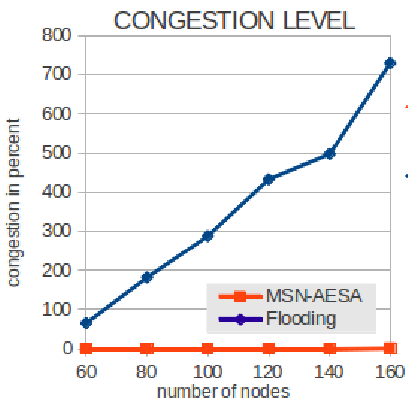

Fig. 8. congestion level of MSN-AESA compared to simple-flooding

MSN-AESA gives nodes' lifespan of almost twofold compared to the simple-flooding. The FND significantly increases from around 610 seconds to 1,200 seconds (197%) and HND increases from around 700 seconds to 1250 (178%) as shown in Fig. 9.

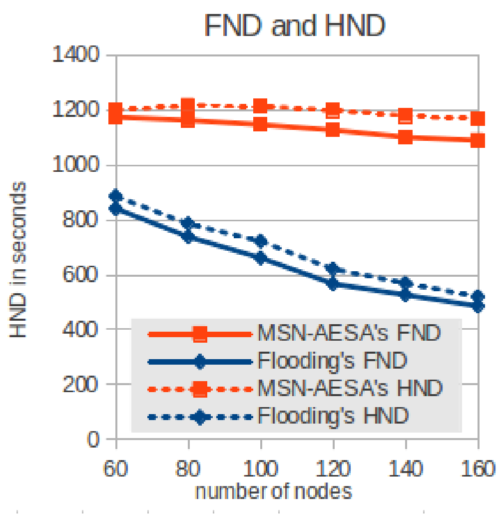

Fig. 9. FND and HND of MSN-AESA compared to simple-flooding

V. CONCLUSIONS

In our proposed algorithm, MSN-AESA contributes to a 10% gain in throughput. To get such additional throughput, transmission/reception range must be set for a minimum of 250 meters, and a maximum number of duplicated message and memory size are limited to a minimum of 10 messages and eight messages respectively. The lifespan of the nodes is extended by almost twofold for the FND and 75% more HND lifetimes. The algorithm also perfectly suppresses congestion to 0%. Furthermore, in contrast to flooding scheme, MSN-AESA algorithm works very well in the dense sensor network as the results suggest that there is no significant degradation for MSN-AESA performance measures.

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