SCALABLE MULTICASTING IN ENERGY AWARE MOBILE BACKBONE
BASED WIRELESS AD HOC NETWORKS

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ABSTRACT
The synthesis of efficient and scalable multicasting schemes for wireless ad hoc networks is a challenging task. In this paper, we present two multicast algorithms that employ a dynamically synthesized Energy-Aware Mobile Backbone Network (E-MBN) to achieve efficient message distribution among members of the multicast groups: (1) Bnet flooding multicast algorithm (BFMA); and (2) shared backbone multicast subnetwork (SBMS). E-MBN incorporates a power saving mechanism that allows inactive nodes to transition into sleep state to conserve energy, and elects nodes with higher energy reserves as backbone nodes to extend network lifetime. For fair comparison, we defined and implemented an extended version of ODMRP with power saving mechanism (ODMRP-PS). We study the throughput (per-watt) performance efficiency of the E-MBN based multicast algorithms through analytical and simulation evaluations, and demonstrate the enhanced performance achieved by these algorithms when compared to ODMRP-PS.

1. INTRODUCTION
Multicasting is an operation that allows the distribution of a message to multiple recipients that are members of a designated multicast group. Many wireless ad hoc/sensor networks include nodes that are highly energy limited. To preserve acceptable operational lifetimes for these nodes, it is essential to employ multicast protocols that minimize nodal energy consumption while providing reliable network transmissions.

Various energy conservation schemes have been introduced to reduce energy consumption of a node through operation optimization. Energy-efficient multicast schemes [10], [11] minimize the total energy cost by adaptively adjusting the radio transmission power levels to construct a minimum-energy multicast tree, whereas maximum lifetime multicast schemes [12], [13] rely on balancing energy dissipation among nodes to maximize the operational lifetime of the network.

TABLE I
ENERGY CONSUMPTION RATES OF LUCENT WAVELAN 802.11 NETWORK INTERFACE CARD

<table>
<thead>
<tr>
<th>State</th>
<th>Sleep (mW)</th>
<th>Idle (mW)</th>
<th>Receive (mW)</th>
<th>Transmit (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47.4</td>
<td>739</td>
<td>901</td>
<td>1.35</td>
</tr>
</tbody>
</table>

The radio control module used by many wireless devices can be modeled to dynamically operate in four key states: sleep, idle, receive, and transmit states. Table 1 illustrates the energy consumption rates of the Lucent WaveLAN 802.11b network interface card, as measured by L. Feeney et al. [9]. The energy consumption of a node when it resides in idle state is only slightly lower than that observed when it resides in receive state. Thus, it is crucial from the energy-saving perspective to switch the radio module off when a node is not in use, rather than only depending on energy optimization multicast schemes.

Traditional multicast protocols for wireless ad hoc networks [5], [6], [7], [8] typically construct a tree or mesh structure that is used to distribute messages to multicast group members. Generally, these implementations impose scalability and efficiency limitations for large networks since they employ protocols that are based on a flat-topology networking architecture. The excessive number of control messages required for maintaining the multicast forwarding structure will cause an increase in packet contention and collisions, resulting in network performance degradation. In [4], we have introduced two hierarchical multicast algorithms that employ a Mobile Backbone Network (MBN) to achieve low overhead and high transmission efficiency. The presented simulation results and mathematical analysis show that our mobile-backbone based multicast algorithms are highly scalable in terms of their performance to variation in nodal mobility, network traffic loading level, and multicast group size.

Energy-Aware Mobile Backbone Network (E-MBN) is an extension to the MBN architecture which incorporates a power saving mechanism that allows inactive nodes to transition into sleep state to conserve energy, and elects nodes with higher energy reserves to act as forwarding nodes to extend the lifetime of the network. The objective of this paper is to present two multicast algorithms that employ a dynamically synthesized E-MBN to achieve energy scalability, i.e. we study the throughput (per-watt) efficiency of the E-MBN based multicast algorithms...
through analytical and simulation evaluations, and examine the network lifetime extension due to the underlying energy conservation scheme. The E-MBN based multicast algorithms under investigation are: (1) Bnet flooding multicast algorithm (BFMA); and (2) shared backbone multicast subnetwork (SBMS). For fair comparison, we have defined and implemented an extended version of ODMRP with power saving mechanism (ODMRP-PS). The specifications and detailed description of ODMRP-PS can be found in the Appendix.

The rest of the paper is organized as follows. In Section II, we provide an overview of the energy-aware mobile backbone network architecture. In Section III, we present the two proposed E-MBN based multicast algorithms. In Section IV, we analytically study the performance of the multicast algorithms. In Section V, we present our simulation results and analysis. Finally, we conclude in Section VI.

II. ENERGY-AWARE MOBILE BACKBONE NETWORK (E-MBN)

Under the MBN architecture [1], nodes belong to one of these two classes: regular nodes (RNs) and backbone capable nodes (BCNs). The backbone network (Bnet) is constructed by dynamically electing BCNs to act as backbone nodes (BNs) and forming backbone links to interconnect neighboring BNs. Such a structure is illustrated in Fig. 1. Each BCN or RN is required to associate with a single BN. A BN and its associated BCNs and RNs will form an access network (Anet).

![Figure 1. Mobile Backbone Network (MBN) Architecture](image)

The Energy-Aware Mobile Backbone Network (E-MBN) is introduced to achieve two objectives: firstly, we want conserve energy by allowing inactive nodes that are not involved in multicasting operation to transition into sleep state; and secondly, we want to extend the lifetime of the network by balancing the energy dissipation of the nodes. The first objective can be achieved by incorporating a MAC layer power saving mechanism into MBN [2]. The specifications and detailed description of E-MBN with power saving mechanism can be found in the Appendix.

In this paper, we assume multicast sources are only active during packet transmissions. For delay-sensitive multicast traffic, the non-backbone receivers will remain active all the time, since they have to be ready to accept any incoming message. However, for delay-insensitive traffic, to achieve even better energy efficiency, we force the receivers to sleep and become active only a fraction of the time. Any incoming message will be buffered at the destination BNs when the intended receivers (that reside in their Anets) are asleep. These BNs will coordinate with the receivers such that the buffered messages will be transmitted to the receivers when they become active. For this paper, this delayed forwarding mechanism works under the assumption that all receivers in the same Anet have the same “wake up” time and duration. Furthermore, it applies only to static or low-mobility networks since a receiver might lose the buffered messages stored in the previously-associated BN when it moves to a new Anet. Nodes utilize average link duration [15] as the mobility metric, since the components required to calculate this metric are readily available in our E-MBN architecture.

The fully-distributed Topology Synthesis Algorithm (TSA) employed herein is a modified version of the one presented in [3]. Although it is desirable to construct a minimum-size Bnet to save energy, TSA without energy awareness will lead to quick energy exhaustion to the backbone nodes, risking a disconnection of the entire network. In order to extend the lifetime of a network, we require an energy aware conversion algorithm that allows the relatively energy-deficient BNs to be converted back to BCNs (so that they can fall asleep) and elect BCNs with higher residual energy to act as BNs. The periodic hello messages in TSA are modified to include nodal residual energy information. Thus, the average 1-hop neighbors’ residual energy for node $u$ is defined as:

$$E_{\text{avg}}(u) = \sum_{v \in \text{deg}(u)} \frac{E_v}{\text{deg}(u)}$$

where $E_v(u)$ is the residual energy of node $u$, and $\text{deg}(u)$ is the degree of node $u$, where $\text{deg}(u) = |N_{\text{BN}}(u) \cup N_{\text{BCN}}(u)|$. $N_{\text{BN}}(u)$ and $N_{\text{BCN}}(u)$ represent the set of 1-hop BN and BCN neighbors of node $u$ respectively. RN neighbors are not included since they are not involved in the Bnet construction. The energy threshold is then found to be:

$$E_{\text{TH}}(u) = \alpha \times E_{\text{avg}}(u)$$

where $0 \leq \alpha \leq 1$ is a multiplicative factor. A BN $u$ will be forced to convert into a BCN when $E_v(u) \leq E_{\text{TH}}(u)$. Under this constraint, the weight of node $u$, $w(u)$ is modified to ensure it will have a lower possibility to become a BN under the TSA conversion criteria. However, in order to maintain Bnet connectivity, node $u$ will remain as a BN until a neighboring BCN is elected to be the new BN.
III. E-MBN BASED MULTICAST ALGORITHMS

Both multicast algorithms use the E-MBN topology synthesis algorithm to dynamically construct a backbone network that provides good coverage for all mobile nodes. This ensures a level of backbone connectivity in response to link failures, nodal failures and nodal mobility.

A. Bnet Flooding Multicast Algorithm (BFMA)

Under BFMA, multicast messages are flooded across the Bnet. Each BN is responsible for copying the multicast packets of interest and distributing them to registered clients in its Anet that are recognized to be members of the message-designated multicast group. Since broadcast messages are relayed only by BNs, the rate of redundant packet transmissions in the network is reduced and the broadcast storm problem [16] is alleviated.

B. Shared Backbone Multicast Subnetwork (SBMS)

The SBMS protocol is a mesh-subnet-based multicast protocol. For each multicast group, every sender constructs a source-based Bnet Shortest Path Tree (BSPT) connecting to all of its designated group members. The superposition of the BSPTs (of the same multicast group) will form the multicast subnetwork for SBMS. The SBMS protocol differs from ODMRP in a number of aspects. Firstly, for multiple sources attached to the same source BN, only a single BSPT is constructed. Secondly, only BNs are capable of becoming forwarding nodes in the multicast subnetwork. Thirdly, the forwarding nodes know the identity of their corresponding 1-hop downstream nodes. Whenever a forwarding node (originator) discovers that one of its downstream nodes is missing (deduced by the non receipt of the corresponding hello messages), a local reconstruction procedure is invoked to repair the link. Fourthly, the topology of the subnetwork is dynamically adjusted through the pruning and grafting of BNs as the latter lose and gain group members in their Anets. When a BN discovers that there is a new multicast member in its Anet, it will construct a link/branch to the closest forwarding node that is a member of the same multicast group. Due to nodal movement, periodic route updates are required to rebuild an optimized multicast subnetwork.

IV. PERFORMANCE ANALYSIS

In this section, we present key performance measures and mathematically characterize bit-per-joule throughput efficiency expressions for the algorithms under evaluation.

A. Multicast Subnetwork (G_M)

An ad hoc network can be represented as an undirected graph \( G = (V_G, E_G) \), where \( V_G \) is the node set and \( E_G \) is the set of links between nodes. We assume nodes to employ omni-directional antennas. Let \( G_M = (V_M, E_M) \subset G \) be the multicast subnetwork, and \( N(G_M) = |V_M| \) be the number of forwarding nodes in \( G_M \). When a multicast packet is transmitted across a designated \( G_M \), only those directly-linked neighboring nodes \( v \in V_M \) will retain and forward these packets. Note that BNs will distribute the packets to their own Anets. For our E-MBN based multicast schemes, let \( G_{Bnet} = (V_{Bnet}, E_{Bnet}) \) be the backbone network graph, where \( N(G_{Bnet}) = |V_{Bnet}| \) be the number of BNs in the Bnet. Since \( G_M \subset G_{Bnet} \), the upper bound for the number of BNs that form the multicast subnetwork is \( N(G_M) \leq N(G_{Bnet}) \).

B. Percentage of Time Receiver is Active (\( \theta_R \))

For each multicast scheme, the total data traffic load applied over all BNs that are members of \( G_M \) is given by:

\[
 f_{data} = \lambda_S \times L_p \times N_S \times N(G_M),
\]

where \( \lambda_S \) represents the average packet arrival rate, \( L_p \) is the average data packet size, and \( N_S \) denotes the number of source nodes for the underlying multicast group. For clarity of presentation we only consider a single multicast group; yet, the presented analysis applies to the combined total loading of multiple multicast groups. The data traffic load contributed by the transmissions of buffered messages:

\[
 f_{buffer} = \lambda_S \times L_p \times N_S \times \beta \times N_{BN}^{Amet}.
\]

where \( \theta_R \) denotes the fraction of time a receiver is active, \( \beta = \left( \frac{1}{\theta_R} - 1 \right) \) is the number of receiver sleep periods, and \( N_{BN}^{Amet} \) represents the number of BNs with receiver in their Anet, which is expressed by:

\[
 N_{BN}^{Amet} \leq \min \left( N(G_{Bnet}), \gamma N_R \right),
\]

where \( \gamma \) is the probability that a receiver is not a BN. As multicast group size increases, the rate of increase for \( N_{BN}^{Amet} \) decreases exponentially since more receivers will be associated to the same Anet, and \( N_{BN}^{Amet} \) is upper-bounded by \( N(G_{Bnet}) \). The overall internal traffic load is calculated to be:

\[
 f_I = f_{control} + f_{data} + \left( \theta_R \times f_{buffer} \right).
\]

Under E-MBN based multicast algorithms such as BFMA, the data rate for an efficiently-loaded network with 100 nodes is in the order of Mbps, whereas the control overhead (consists only of the TSA’s 1-hop hello messages) is:

\[
 f_{control} = N \times (L_C / \text{update interval})
\]

\[
 = 100 \text{ nodes} \times (400 \text{ bits} / 1 \text{ sec}) = 40 \text{ kbps},
\]

where \( N \) is the total number of nodes in the network and \( L_C \) is the average control packet size.

The network’s normalized internal loading ratio, which is used to express the fraction of the overall internal transport capacity that is occupied by multicast traffic, is:

\[
 \tau = \frac{f_I}{SRF \times R}.
\]

where \( SRF \) denotes the network’s spatial reuse factor and
R is the channel’s link layer data rate. Based on (3) – (6), we will be able to determine a feasible $\theta_R$ such that the network is not overloaded by the sudden influx of buffered messages during the times when the receivers are active.

C. Number of Active Nodes ($N_a$)

For E-MBN based multicasting, all BNs must be active all the time, regardless of whether they are selected to be in $G_{MB}$. The rest of the nodes will be asleep unless a node is a non-backbone receiver that is active. Thus, the average number of active nodes is:

$$N(G_{MB}) \leq N_a \leq \max(N(G_{MB}) + \gamma N_R \theta_R, N),$$  \hspace{1cm} (7)

For ODMRP-PS:

$$N(G_M) \leq N_a \leq \max(N(G_M) + \gamma^* N_R, N),$$  \hspace{1cm} (8)

where $\gamma^*$ is the probability that a receiver is not a node selected to be in the forwarding mesh.

D. Energy Consumption Rate ($W$)

For our approximate analysis, we assume the energy consumption rates for a node in receive state to be the same as that incurred when it is in active idle state. Also, we neglect the energy consumption rate when a node is in sleep state, since it is significantly smaller than the energy consumption rates incurred when a node is in other states. The energy consumption rate for a node that is in the active non-transmission state is $W_r$ watts, while the energy consumption rate in the transmission state is $W_t$ watts. The energy consumption rate can be contributed by:

(i) Nodes during periods that are transmitting packets.

(ii) Nodes that are active (either in idle or receive state) but are not in the transmission state.

(iii) Nodes during the control and management period.

The average energy consumption rate $W$ is given as:

$$W = (1-\varepsilon) \left[ \frac{f_{sk} + f_{sk} + f_{sk}}{R} \right] W_r + N_a (1-\rho) W_t + \varepsilon [ \zeta W_r + (1-\zeta) N W_r ]$$

$$= (1-\varepsilon) \left[ N_a W_r + N_a \rho (W_t - W_r) \right] + \varepsilon \left[ N W_r + N \zeta (W_t - W_r) \right],$$

where

$$\rho = \frac{\lambda_s L_s N_s N_R}{N_a R}$$

is the fraction of time an active node stays in the transmission state, $\varepsilon$ represents the fraction of time a node stays in the C&M state, and $\zeta$ denotes the fraction of time a node is transmitting control messages during the C&M period. In our simulation scenario (as seen from the Appendix), the transmission time of a hello message is equal to 0.44ms, with a hello period duration of 50ms. Thus, $\zeta$ is a very small number. The average energy consumption rate is simplified to be:

$$W = (1-\varepsilon) \left[ N_a W_r + N_a \rho (W_t - W_r) \right] + \varepsilon [ N W_r ].$$  \hspace{1cm} (9)

E. Bit-Per-Joule Throughput Performance

The bit-per-joule throughput efficiency performance for ODMRP-PS and E-MBN based multicast algorithms is identified as the ratio between the total multicast throughput ($f_{TH}$) measured at the multicast receivers and the average energy consumption level from (9):

$$Z = \frac{f_{TH}}{W} = \frac{\lambda_s L_s N_s N_R}{(1-\varepsilon) \left[ N_a W_r + N_a \rho (W_t - W_r) \right] + \varepsilon [ N W_r ]}.$$  \hspace{1cm} (10)

This analytical expression is used to compare with the bit-per-joule simulation result in Section V.

V. SIMULATION RESULTS AND ANALYSIS

The simulation models of the proposed multicasting schemes were implemented in QualNet. The Distributed Coordination Function (DCF) of IEEE 802.11 is used as the MAC layer protocol. We assume the network contains 100 nodes that roam in an area of dimensions given by $1500m \times 1500m$. Each node is equipped with a wireless radio that operates at a data rate of 2 Mbps, with an effective radio transmission range of 300m. The multicast protocol parameter values can be found in Table 2. The inter-arrival time of data packets for each sender is exponentially distributed, with an average of 0.5 seconds. The average data packet size is equal to 512 bytes. The radio power levels are selected to be $W_r = 900mW$ and $W_t = 1300mW$.

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>MAJOR PROTOCOL PARAMETER VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODMRP-PS</td>
<td>Join-Query Refresh Interval</td>
</tr>
<tr>
<td>MBN-TSA</td>
<td>Hello Message Interval</td>
</tr>
<tr>
<td>SBMS</td>
<td>Subnetwork Refresh Interval</td>
</tr>
</tbody>
</table>

A. Bit-Per-Joule Performance

The bit-per-joule throughput efficiency performance achieved under different number of senders is plotted in Fig. 2, showing results obtained by simulation as well as from our mathematical expression in (10). Both our E-MBN based multicast algorithms are better than ODMRP-PS because they employ a backbone network to limit the number of forwarding nodes, leading to a smaller number of active nodes as compared to that incurred by ODMRP-PS. It is commonly assumed that SBMS should have a better bit-per-joule performance because fewer nodes are required to retransmit the multicast messages. However, in terms of energy consumption, we observed from Fig. 2 that both simulation and analytical results show that SBMS has similar performance as BFMA. This observation has lead to the conclusion that number of active nodes $N_a$ for a multicast algorithm is the major contributing factor since both of our multicast algorithms have similar number of active nodes, i.e. the BNs that form the Bnet, resulting in similar bit-per-joule performance. In addition to that, it is
noted that SBMS has a slightly longer average $C&M$ period (where every node is awake to perform the exchange of hello message under E-MBN) than BFMA since SBMS uses periodic multicast route updates to maintain an optimized multicast subnetwork.

![Figure 2. Bit-Per-Joule Performance vs. Number of Senders](image)

For a static or low mobility network (with nodal movement of $1 \sim 2$ m/s), we can improve the Bit-Per-Joule performance by using the delayed forwarding mechanism with our E-MBN based multicast algorithms. From Fig. 3, as the multicast group size increases (represented as the increase in number of multicast receivers in our simulation), we observed significant Bit-Per-Joule improvement relative to the case where receivers are always active ($\theta_R = 100\%$), as we decrease the fraction of time receivers are active. However, when number of receivers is small (e.g. $N_R = 10$), the Bit-Per-Joule improvements are negligible. This is because the number of active nodes, $N_a$ is dominated by $N(G_{Bin})$, as shown in (7). This leads to energy consumption, $W$ to be dominated by the backbone nodes. Based on this analysis, we are able to use the multicast group size information to determine the best scenario to utilize the delayed forwarding mechanism to optimize the Bit-Per-Joule improvement.

![Figure 3. Bit-Per-Joule Improvements vs. Number of Receivers](image)

The delay-throughput performance curve is plotted in Fig. 4. The delay depicted is the average end-to-end delay experienced by a packet, whereas the throughput represents the throughput level averaged over all multicast receivers. The results show the superiority of BFMA ($\theta_R = 100\%$) over ODMRP-PS under high network loads. For low network loads, both algorithms achieve similar performance. The BFMA ($\theta_R = 50\%$) scheme achieves, as expected, worse performance than that attained by using BFMA ($\theta_R = 100\%$) due to the excess delays incurred by the buffering of messages waiting for distribution at the destination BNs. Under low network loads, we observed that BFMA ($\theta_R = 50\%$) achieve a slightly worse performance than ODMRP-PS. However, it has an advantage over ODMRP-PS under high network loads.

![Figure 4. Delay-Throughput Performance Curve](image)

B. Network Lifetime Extension

The objective of energy conservation is to help extend the lifetime of a network with energy-limited nodes. It is desirable to balance energy dissipation of these nodes so that they would not run out of energy early in some area, resulting in a disconnection of the entire network. In this scenario, each node is given a limited energy of 40J. Although different definitions of network lifetime have been used, we assume network lifetime for ad-hoc networks to be represented by a packet delivery ratio (PDR) threshold of 70%, since this indicates the surviving nodes can no longer connect the network effectively. Under this criterion, we observed from Fig. 5 that BFMA extends the lifetime of a network by 75% beyond that of ODMRP-PS. For sensor networks, we consider network lifetime as the duration before the first node in the network is dead. The corresponding results can be obtained from Fig. 6. A summary of network lifetime comparisons is presented in Table 3.

<table>
<thead>
<tr>
<th>NETWORK LIFETIME MEASUREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODMRP-PS</td>
</tr>
<tr>
<td>1st Node Dead</td>
</tr>
<tr>
<td>PDR 70%</td>
</tr>
</tbody>
</table>

We observed from Fig. 6 that BFMA has a significantly higher number of alive nodes as compared to ODMRP-PS. This is important since a higher number of alive nodes will achieve better area coverage (in sensor networks), and in a dynamic scenario (for ad-hoc networks), nodes with energy could possibly move into an area to replace other nodes that run out of energy to maintain network connectivity.
VI. CONCLUSIONS

In this paper, we propose two hierarchical multicast algorithms that employ an energy-aware mobile backbone network that achieve energy and multicast forwarding scalability. Through a series of analytical derivations and simulation based evaluations, our results show that E-MBN based multicast algorithms achieve better bit-per-joule and delay-throughput performances as compared to ODMRP-PS. The mobile backbone enables our multicast algorithms to construct smaller multicast subnetworks, resulting in better multicast forwarding efficiency and energy conservation. In order to extend the lifetime of a network, an energy-aware topology synthesis algorithm is implemented to balance energy dissipation of the nodes that form the mobile backbone. Our results show that BFMA extends the lifetime of a network by 75% beyond that of ODMRP-PS.

APPENDIX

A. E-MBN Power Saving Scheme

In this appendix we provide a detailed description of the E-MBN power saving scheme. The specifications for this scheme build on top of the IEEE 802.11 power saving mode and the hello message exchange process used by our topology synthesis algorithm (TSA). Under TSA, each node periodically issues hello messages to learn its link-layer neighbors. In our E-MBN power saving scheme, BNs are kept awake all the time to coordinate the sleeping/suspending schedules among its local non-backbone nodes located in their corresponding ANets.

Nodes are synchronized to wake up at the beginning of each super frame. The time duration of a super frame is determined by the underlying multicast protocol, which is selected to be 1 second in our implementation. We note that accurate frame synchronization acquisition is only required for the interaction between neighboring nodes. The synchronization mechanisms in [14] requires nodes that are members of a minimum connected dominating set (MCDS) to send synchronization beacons, and readily incorporated into our E-MBN power saving scheme.

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state to conserve energy when it is not engaged in any packet transmission or reception activity. The duration in which a node stays in sleep state can be selected individually by each node. At the end of its sleep state duration, the node transitions into the C&M state. The sleep state duration is set to be 900 ms.

B. ODMRP Power Saving Protocol (ODMRP-PS)

On-Demand Multicast Routing Protocol (ODMRP) [6] is a mesh-based multicast protocol that uses the forwarding group concept to select, for each multicast group a limited set of nodes for forwarding multicast messages. A Join-Query packet is periodically broadcasted to update the election of forwarding group members and refresh the end-user group membership information. The state transition diagram of the finite state machine for ODMRP with power saving mechanism (ODMRP-PS) is shown in Fig. 8.

Although the exchange of hello messages is not required for ODMRP-PS, nodes are still required to synchronize to wake up at the beginning of each super frame. Note that the period of the super frame is equivalent to the refresh interval of ODMRP. Again, accurate frame synchronization acquisition is only required for the interaction between neighboring nodes. In the original protocol, Join Query messages are piggybacked in data packets and flooded across the whole network as part of the operation that constructs the multicast forwarding mesh. In our implementation, we decoupled the control and data forwarding mechanism of ODMRP to make the protocol more scalable, since the flooding of a relatively big data packets is undesirable. The decoupling also ensures a shorter interval for the sources to obtain Join Replies back from the receivers (the Query-and-Reply phase is performed in the C&M state), since the control packets have a higher priority than data packets. However, the C&M state duration will depend on the size of network since it has to accommodate the round-trip time of the Query-and-Reply packets.

Once the Query-and-Reply phase is finished in the C&M state, a forwarding mesh is constructed. The selected forwarding nodes will transition into active state since they are responsible for data transmissions, while the non-forwarding nodes will transition into sleep state to conserve energy. In other words, the wakeup notifications for ODMRP-PS are embedded in its Query-and-Reply phase. In our simulation, the time duration of a super frame for ODMRP-PS is set to be equal to its refresh interval (which in this case is 3 seconds). We have set the C&M state duration to be 300 ms and this has proven to be sufficiently long for accommodating the round-trip time required by the Query-and-Reply phase for the underlying simulation network size and conditions, whereas the sleep and active state durations are both set to be 2.7 seconds.

REFERENCES


