

Multicasting in Energy-Aware Mobile Backbone Based Wireless Ad-Hoc Networks



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 - Extended Shortest Path Multicast Tree (E-SPMT)
 - Hybrid Multicast Algorithm (HMA)
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- Performance Evaluations
 - Mathematical Analysis
 - Simulation Results



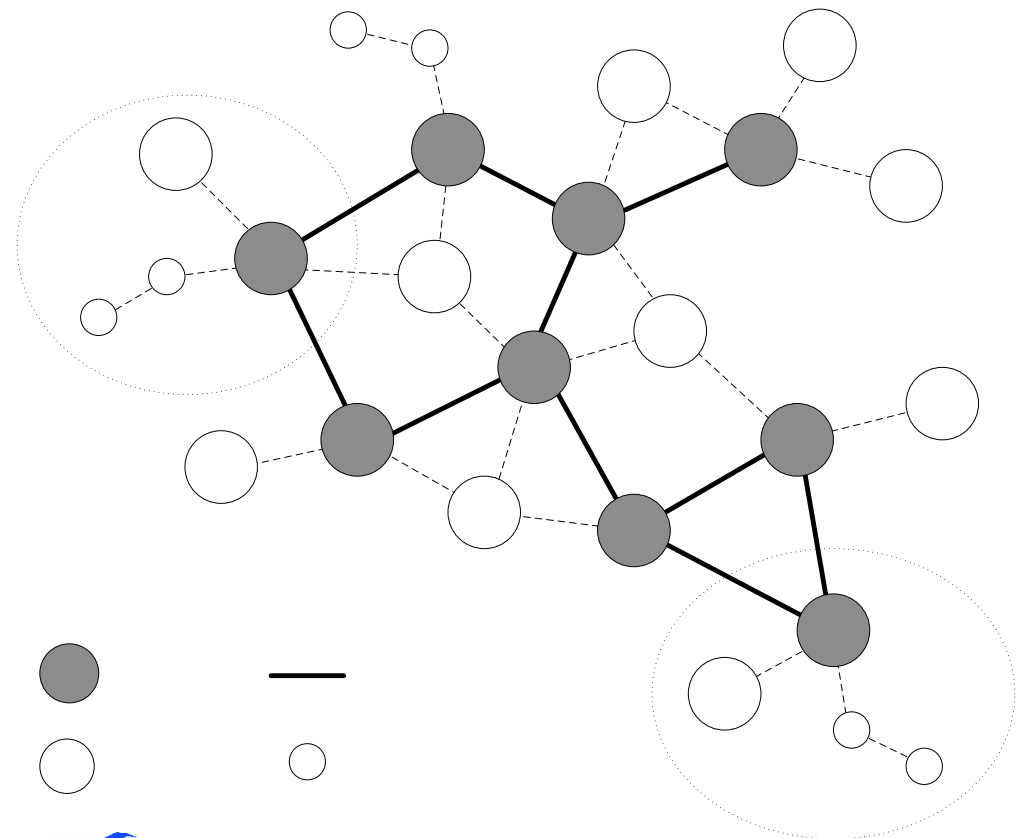
Objectives and Motivations

- A mobile ad hoc network (MANET) is a dynamic self-configurable wireless network with no fixed infrastructure or centralized administration.
- Multicasting is an operation that allows the distribution of a message to multiple recipients that are members of a designated multicast group.
- We present three hierarchical multicast algorithms that employ an Energy-Aware Mobile Backbone Network (E-MBN) to achieve the following objectives:
 - ***Efficient message distribution*** by reducing the number of redundant packet forwarding.
 - ***Energy conservation*** for energy-limited nodes by allowing inactive nodes to transition into sleep state.

Mobile Backbone Network (MBN)

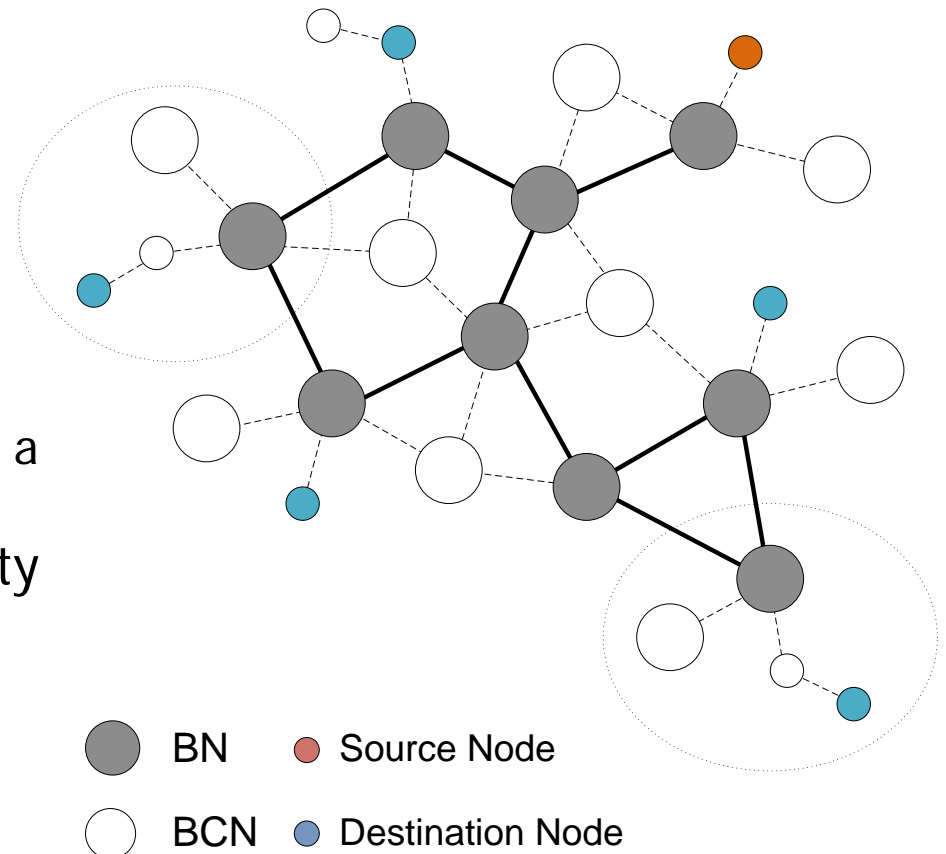
References: See papers by I. Rubin et. al on Mobile Backbone Networks (MBNs) that serve heterogeneous nodal types.

- Two categories of nodes:
 - Backbone Capable Nodes (BCNs)
 - Regular Nodes (RNs)
- Backbone Network (Bnet):
 - Backbone nodes (BNs) are elected from BCNs
- Access Network (Anet):
 - Consists of a BN and its associated clients



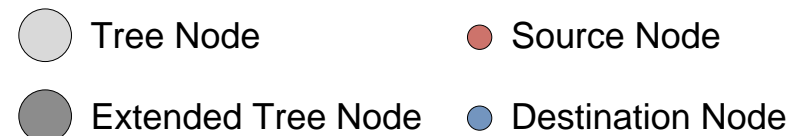
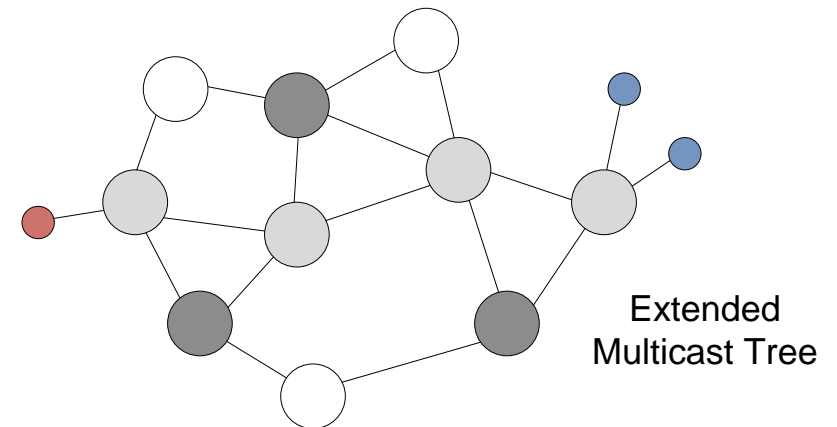
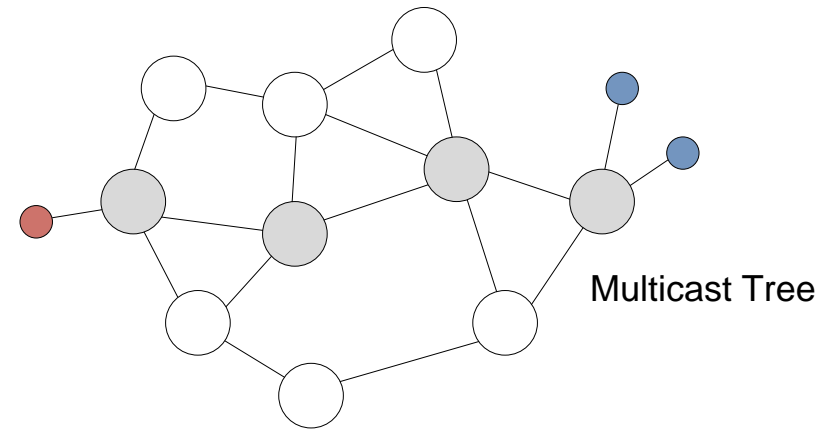
Bnet Flooding Multicast Algorithm (BFMA)

- Protocol Description:
 - The source BN floods each multicast message across the backbone network.
 - All BNs participate in forwarding the multicast message.
 - Each BN will only forward a single copy of message.
 - Highly robust under mobility induced topology changes, and achieves excellent delay-throughput performance when the distribution scope is sufficiently high.



Extended Shortest Path Multicast Tree (E-SPMT)

- Protocol Description:
 - A multicast tree is the optimal distribution structure when:
 - No nodal mobility,
 - The distribution scope is small or limited.
 - Since a tree structure is easily broken under nodal mobility, additional forwarding nodes are selected and integrated into the original multicast tree, creating an extended multicast tree.





Hybrid Multicast Algorithm (HMA)

- Protocol Description:
 - Due to the diversity of applications of ad hoc networks, a hybrid multicast algorithm with multi-behavioral mode of operations is desirable.
 - HMA is a hybrid BFMA/E-SPMT multicast algorithm in which the multicast structure dynamically adapts to the observed underlying network and multicast group membership conditions.
 - The algorithm uses:
 - BFMA when there is a large number of multicast receivers that scatters across the network, and to provide a high level of robustness to mobility.
 - E-SPMT when the distribution scope is determined to be limited.

Energy-Aware Mobile Backbone Network (E-MBN)

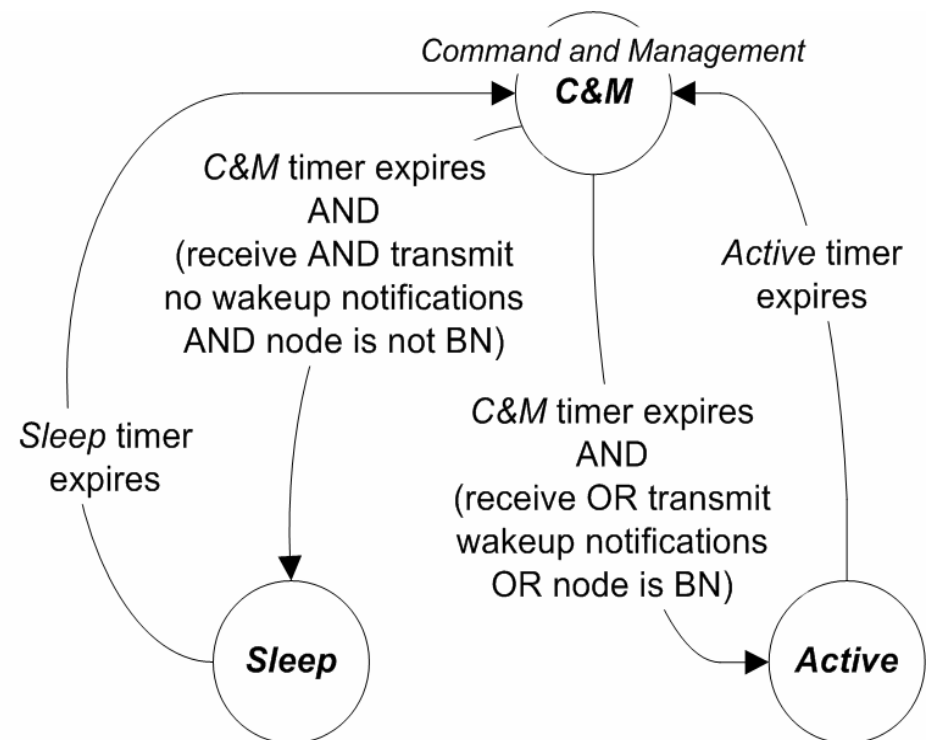
- Existing energy conservation mechanisms for ad hoc networks can be classified into two categories:
 - Active energy conservation schemes
 - Passive energy conservation schemes
- The radio module has four operational states: *sleep*, *idle*, *receive*, *transmit*. Energy consumption in idle state is only slightly lower than that observed when in transmit or receive states.
- Thus, it is desirable to switch the radio module into sleep state when a node is not in use.

Sleep	Idle	Receive	Transmit
47.4 mW	739 mW	901 mW	1.35 W

Energy Consumption Rates of the Lucent WaveLAN 802.11b Network Interface Card

E-MBN: Energy Conservation

- BNs are kept awake all the time to coordinate the sleeping/suspending schedules used by local non-backbone nodes located in their corresponding Anets.
- Nodes are synchronized to wake up periodically at the beginning of each super frame, and broadcast *hello* messages to their neighboring nodes.
- Wake/Sleep notifications are included in these *hello* messages.





Multicast Performance Measures

- Analytical models are developed to compare the performance of our MBN-based multicast algorithms.
- Analytical evaluations are performed to cross-validation with our simulation results.
 - Backbone Network Size
 - **Multicast efficiency factor**
 - Number of awake nodes
 - Energy Consumption Rate
 - **Bits-Per-Joule Performance**

Multicast Efficiency Factor

Data traffic/transport load

$$f_{data} = \lambda_s \times L_p \times N_s \times N(G_M)$$

Control traffic load (for BFMA)

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

Overall internal multicast traffic load

$$f_I = f_{data} + f_{control}$$

Multicasting efficiency factor

$$\eta = \frac{f_{TH}}{f_I} = \frac{(\lambda_s \times L_p \times N_s \times N_R)}{f_I}$$

Number of nodes, $N = 100$

Number of senders, $N_s = 5$

Number of receivers, $N_R = 10$

Average data packet size, $L_p = 512$ bytes

Average packet arrival rate, $\lambda_s = 2$ msg/s

Average control packet size, $L_C = 50$ bytes

Size of multicast forwarding structure, $N(G_M)$

	BFMA	E-SPMT	ODMRP
$N(G_M)$	21	15	31
f_{data}	860 kbps	615 kbps	1.27 Mbps
$f_{control}$	40 kbps	50 kbps	35 kbps
η	0.46	0.57	0.32



Energy Consumption Rate

- The energy consumption rate for a node that is in the awake non-transmission state is W_r watts, while the energy consumption rate in the transmission state is W_t watts.
- The energy consumption rate (W) consists of three components:
 - Contributed by nodes during periods that they are transmitting packets.
 - Contributed by nodes that are active (either in idle or receive state) but are not in the transmission state.
 - Contributed by nodes during the control and management state (when handling control messages).



Energy Consumption Rate (cont.)

$$\begin{aligned}
 W &= (1 - \varepsilon) \left[\left(\frac{N(G_M) \lambda_S L_P N_S}{R} \right) W_t + N_a (1 - \rho) W_r \right] + \varepsilon \left[\zeta W_t + (1 - \zeta) N W_r \right] \\
 &= (1 - \varepsilon) \left[N_a W_r + N_a \rho (W_t - W_r) \right] + \varepsilon \left[N W_r + N \zeta (W_t - W_r) \right] \\
 &\approx (1 - \varepsilon) \left[N_a W_r + N_a \rho (W_t - W_r) \right] + \varepsilon \left[N W_r \right] \\
 \text{where } \rho &= \frac{N(G_M) \lambda_S L_P N_S}{N_a R}
 \end{aligned}$$

Notation:

R = channel capacity

ρ = fraction of time an active node stays in transmission state

ε = fraction of time a node stays in control & management (C&M) state

ζ = fraction of time a node is transmitting control msg. in C&M state



Bits-Per-Joule Performance

- The bits-per-joule throughput efficiency performance measure is the ratio between the total throughput measured at the multicast receivers (f_{TH}) and the average energy consumption level (W).

$$\chi = \frac{\lambda_S L_P N_S N_R}{(1 - \varepsilon) [N_a W_r + N_a \rho (W_t - W_r)] + \varepsilon [N W_r]}$$



Simulation Scenario Setup

- Simulation Environment

MAC Layer Protocol	IEEE 802.11b
Channel Capacity	2 Mbps (Single Freq. Band)
Radio Transmission Range	250m
Simulation Duration	300 seconds
Network Dimension	1500m × 1500m
Number of Nodes	100
Data Packet Size	512 bytes

- Major Protocol Parameters

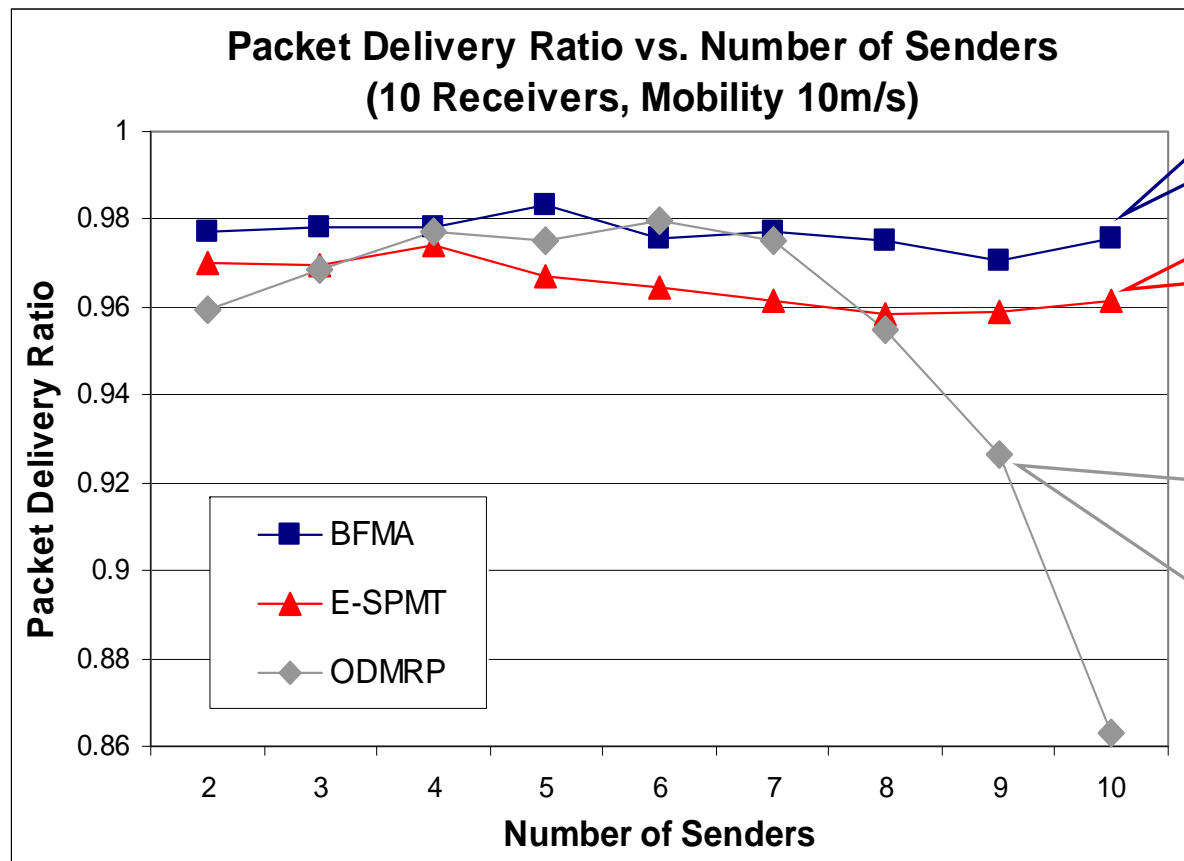
ODMRP-PS	Join-Query Refresh Interval	3 seconds
MBN-TSA	Hello Message Interval	1 seconds
E-SPMT	Subnetwork Refresh Interval	10 seconds



Simulation Setup

- Multicast Algorithm Comparisons
 - The simulation network consists of 100 nodes.
 - A random waypoint mobility model is employed with nodal movement speed of 10 m/s.
 - Single multicast group is simulated.
 - The multicast senders represent incoming network flows, each with an average (exponentially-distributed) inter-arrival time of 0.5 s.

Packet Delivery Ratio

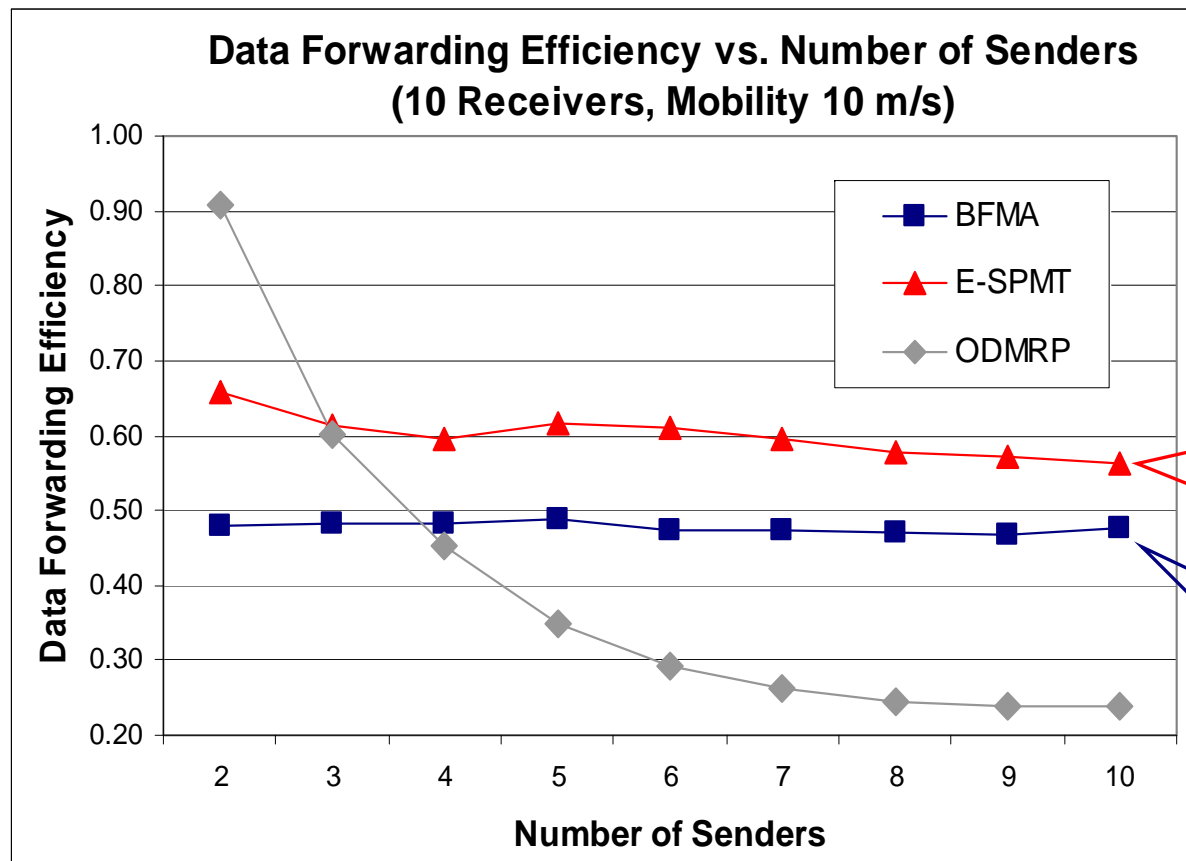


BFMA achieves high delivery ratio through flooding in the Bnet.

E-SPMT maintains its efficiency with a multicast tree.

The PDR for ODMRP degrades faster due to its less efficient data forwarding mechanism, i.e. ODMRP does not scale well with large number of multicast senders.

Data Forwarding Efficiency

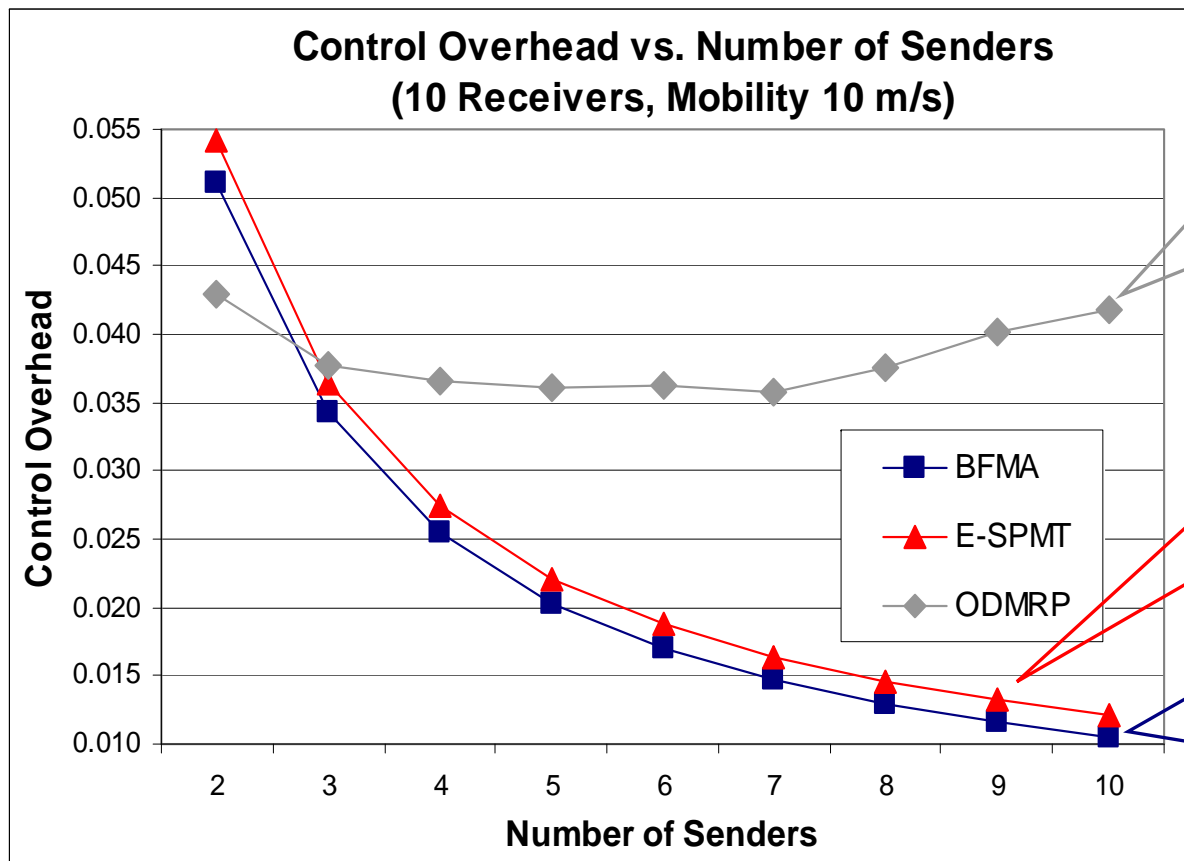


The E-MBN based multicast algorithms achieve excellent data forwarding efficiency due to the use of Bnet.

E-SPMT exhibits the best result since it uses a more efficient multicast structure.

BFMA restricts the flooding of multicast messages to the Bnet.

Control Overhead

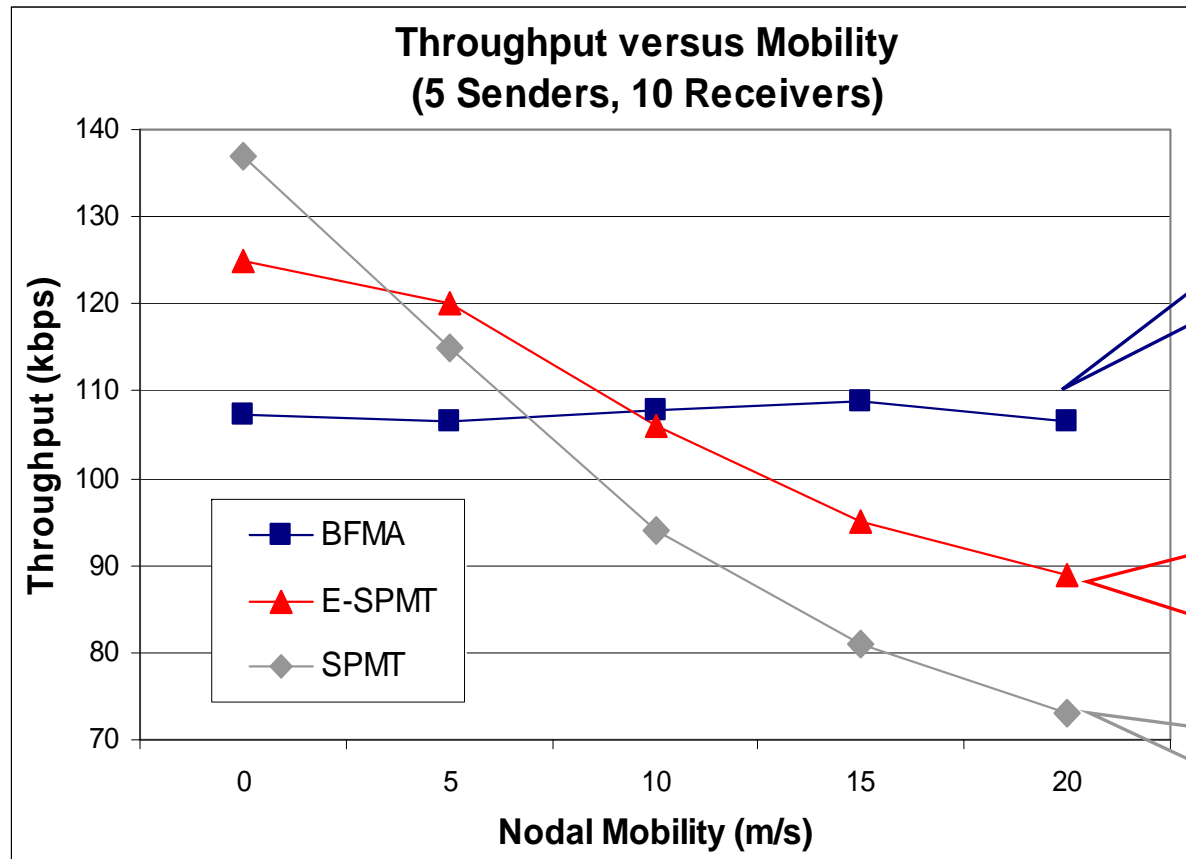


ODMRP does not scale well with large number of senders due to its per-source periodic updates.

E-SPMT has higher control overhead than BFMA because they require the use of periodic updates.

The control overhead of BFMA consists only of *hello* messages that maintain the MBN layout and operation.

Relationship: Throughput and Robustness

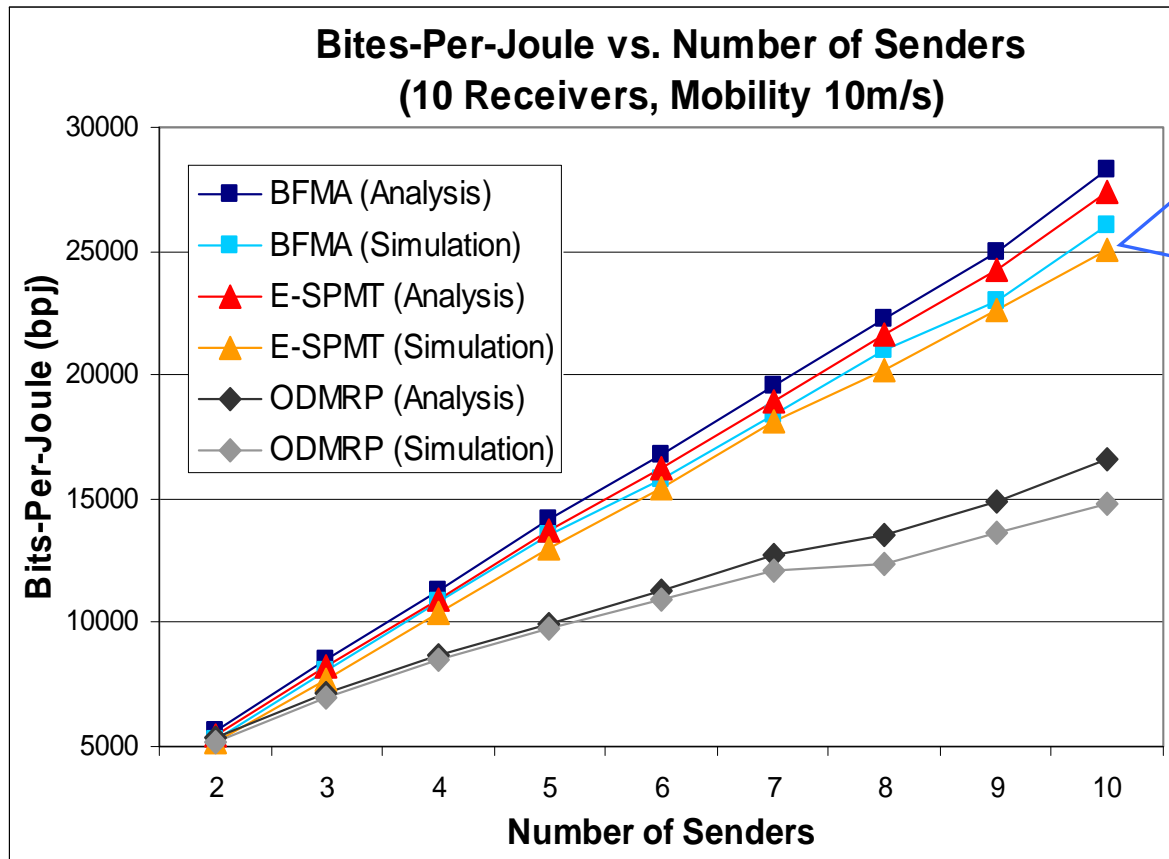


BFMA is extremely robust under high nodal mobility.

E-SPMT elects additional forwarding nodes to generate sufficient robustness for low-to-medium mobility scenarios.

SPMT breaks easily when nodal mobility increases.

Bits-Per-Joule Performance



Although BFMA and E-SPMT have similar number of awake nodes (BNs), E-SPMT has a slightly longer *C&M* period (where every node is awake).

Our multicast algorithms are more efficient than ODMRP since 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.



Conclusions

- We propose three hierarchical multicast algorithms that employ a Mobile Backbone Network to achieve efficient message distribution among members of multicast groups.
- We incorporated a power savings mechanism into our Energy-Aware Mobile Backbone Network (E-MBN) to achieve energy conservation by allowing inactive nodes to transition into sleep state.
- Through a series of analytical derivations and simulation based evaluations, the performance characteristics of these algorithms are compared.
- Our results show that our E-MBN based multicast algorithms achieve better data forwarding efficiencies, control overhead and bits-per-joule performances than the flat-topology based ODMRP-PS.