Receiver-based Protocol Enhancements for Wireless Ad-Hoc and Sensor Networks

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Contributions of Thesis

- Receiver-based protocols enhancements in multicast.
- Receiver-based protocols enhancements in convergecast.

- Introduction and Background
- RBMulticast Enhancements and Performance
- Energy-efficient Duty Cycle Assignment
- Future Work

Receiver-based Protocols

- All receivers contend to be the next-hop router when they hear a packet route request, and the transmitter selects the receiver that is optimum according to some set criteria (e.g., the node that is closest to the sink) as the next hop.
- Advantages:
  - Remove the need for costly state maintenance
  - Do not require synchronization of node's sleep-awake schedules for duty cycling.

Receiver-based Protocols (Cont.)

- The approach:
  - The transmitter sends an RTS packet with the location of the transmitter and the sink.
  - Receivers calculate their distance to the sink.
  - After a delay, nodes send a CTS packet back to the transmitter.
  - The first node that sends the CTS packet is selected as the next hop.
  - The transmitter forwards the data packet to that node.
- Related Work
  - IGF (Implicit Geographic Forwarding): a coefficient consists of the weight of distance, energy and random parameters.
  - GeRaF (Geographic Random Forwarding): provide the analysis for the performance of energy consumption, latency and multihop.
  - XLM (Cross-layer Module): take the link quality into consideration.

Receiver-based Protocols (Cont.)

- The methods in the receiver-based protocol applied in my projects: the relay region (locations with geographic advancement to the sink) is averagely divided into *Np* priority regions. *Nr* CTS contention slots are assigned in each priority region.

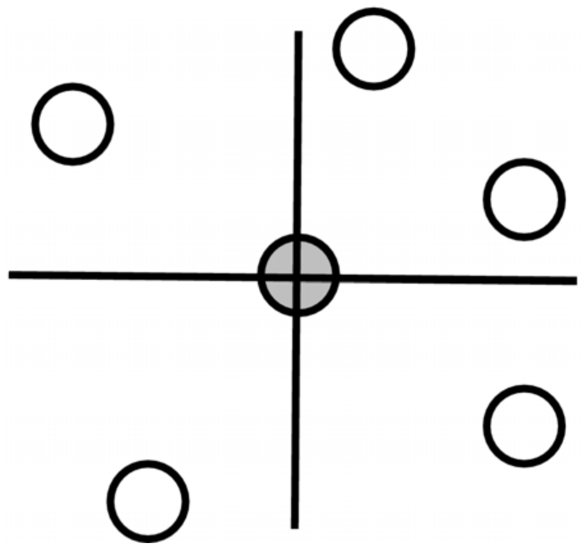
Communication patterns observed in networks

- Broadcast: a source node sends data to the entire network
- Multicast: a source node sends data to a subset of the nodes in the entire network
- Unicast: a source node sends data to a single sink
- Convergecast: all source nodes send data to a single sink

- Introduction and Background
- RBMulticast Enhancements and Performance
  - RBMulticast Overview
  - RBMulticast Performance Enhancements
  - RBMulticast Performance Evaluation
- Energy-efficient Duty Cycle Assignment
- Conclusion and Future Work

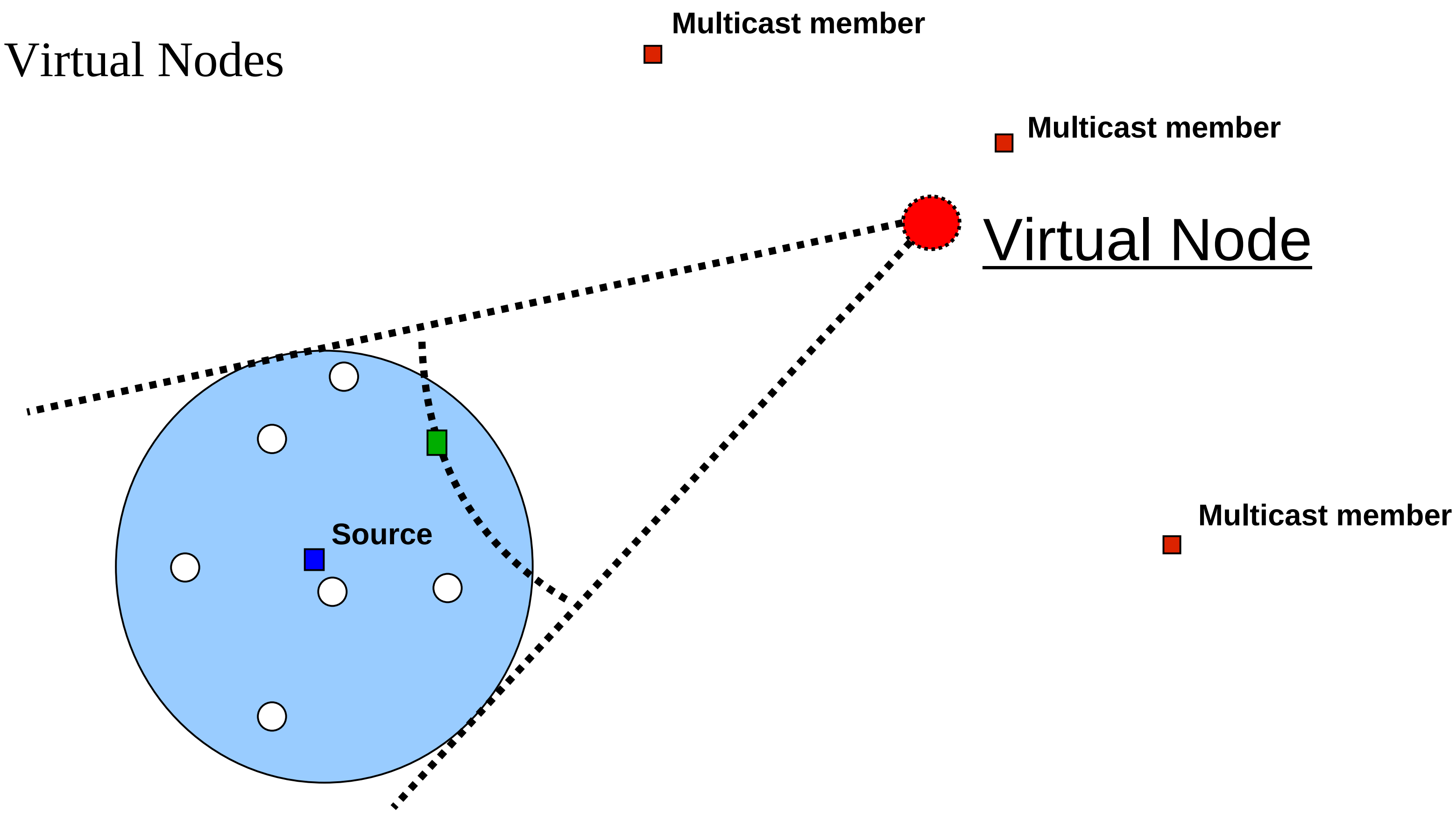
RBMulticast Overview

- RBMulticast is based on XLM, which is a receiver-based unicast protocol.
- Multicast Regions



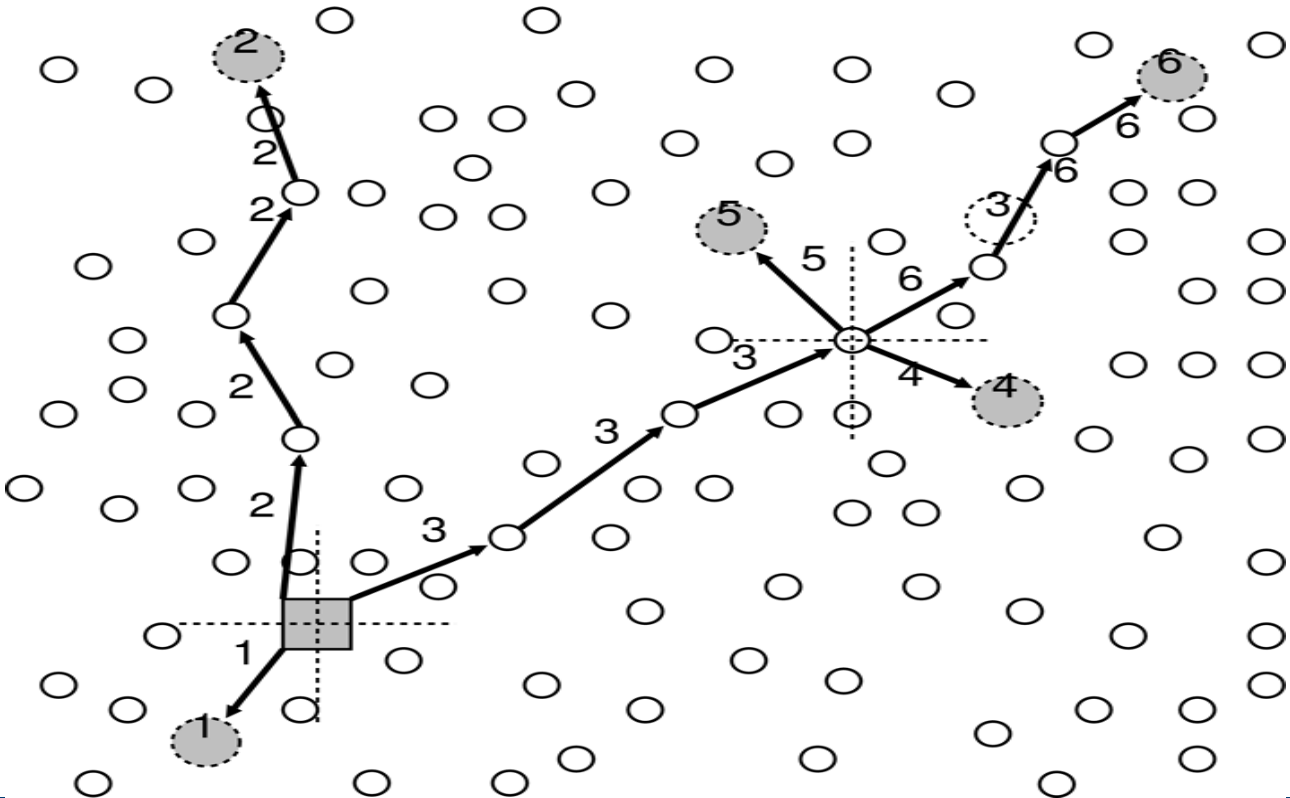
RBMulticast Overview (Cont.)

- Virtual Nodes



RBMulticast Overview (Cont.)

- An example



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  - RBMulticast Performance Evaluation
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RBMulticast Performance Enhancements

- Split packet contention problem in RBMulticast and the proposed solution
  - After replication, all the packets generated are immediately inserted into the node's buffer to be transmitted. The relay nodes receiving packets contend with the rest replicated packets.
  - A proposed solution: split packet time interval (SPTI) is used between transmissions destined to different regions.
- Performance Evaluation

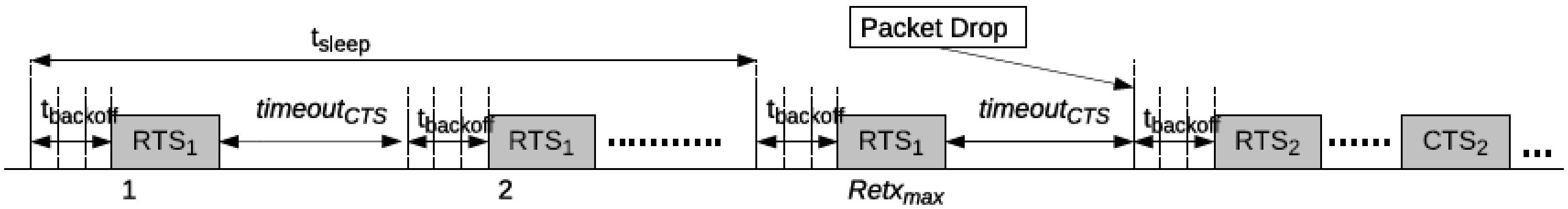
SPTI (sec)	0	0.05	0.08	0.125	0.25
PDR	0.75	0.88	0.94	0.95	0.95

RBMulticast Performance Enhancements

- MAC-level Duty Cycling Improvements
  - To guarantee reaching a relay candidate if one exists, all retransmissions should be spread to a duration larger than the maximum sleep duration of the nodes, i.e.,

$$t_{sleep} \leq Retx_{max} \times (t_{backoff} + timeout_{CTS})$$

where t_{sleep} is the sleep duration, $Retx_{max}$ is the maximum number of RTS retransmissions, $t_{backoff}$ is the expected backoff time for contention, and $timeout_{CTS}$ is the timeout duration a node will wait to receive a CTS.



RBMulticast Performance Enhancements

- Each of *Nr* CTS contention slots in one priority region is set to be the duration of sending one CTS packet.

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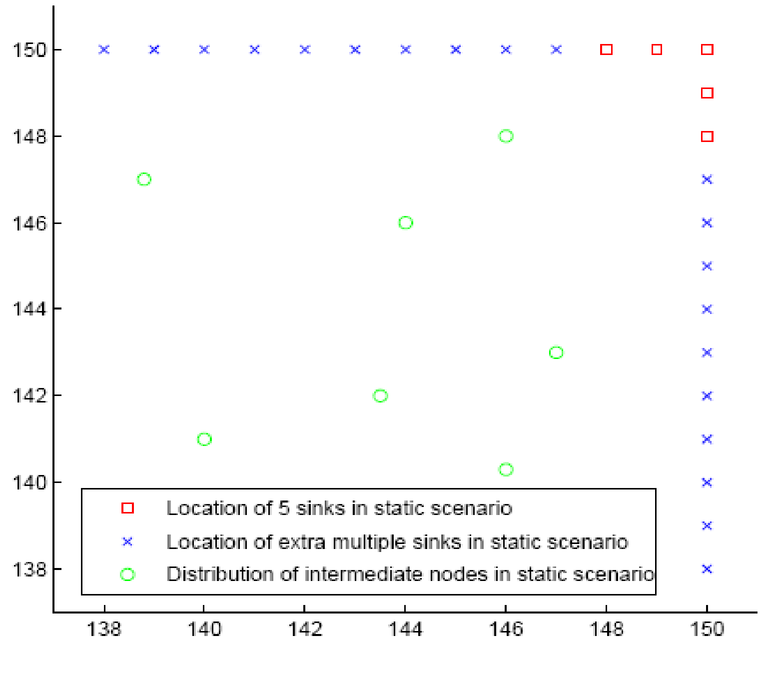
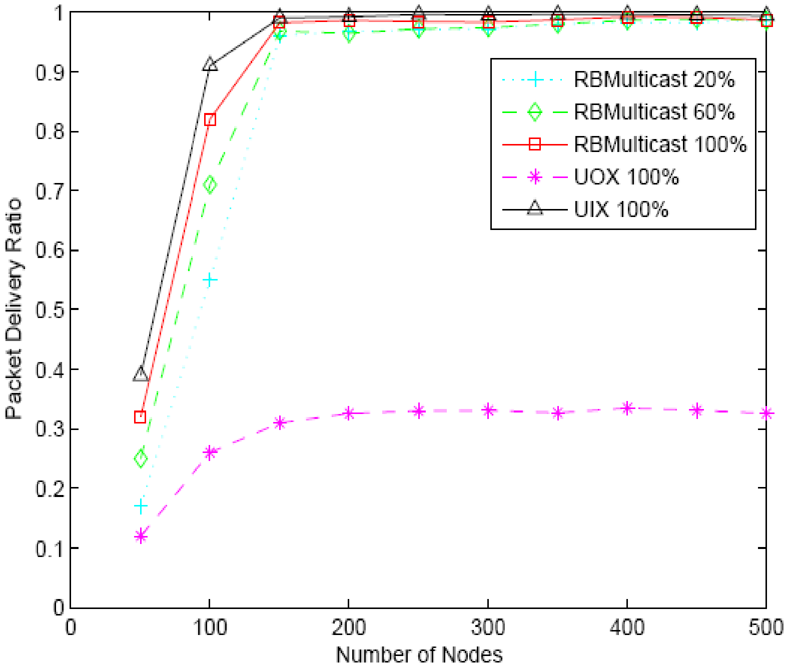
RBMulticast Performance Evaluation

- area = 150m $\times$ 150m.
- Transmission range = 30m
- Interference range ~= 80m.
- SPTI = 0.1 s.
- Investigated methods:
  - RBMulticast
  - UOX: Unicast based on the original XLM MAC.
  - UIX: Unicast based on the improved XLM MAC.

Static Nodes, Five Sinks

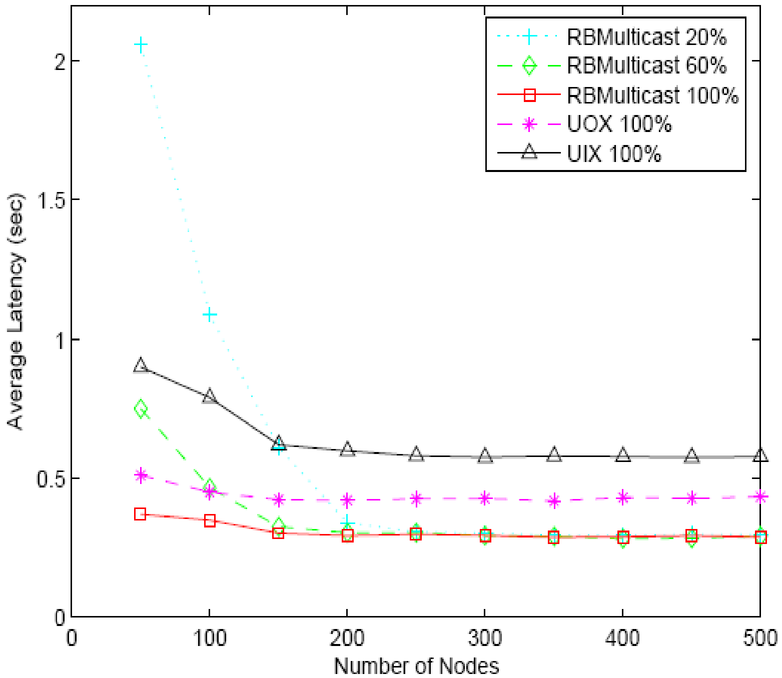


Locations of the sinks

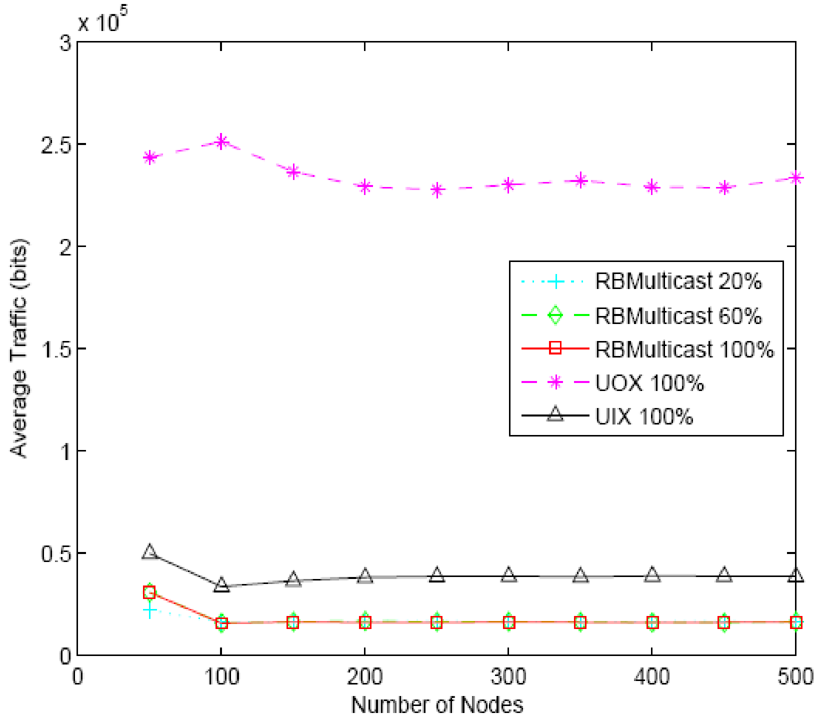


Packet delivery ratio

Static Nodes, Five Sinks

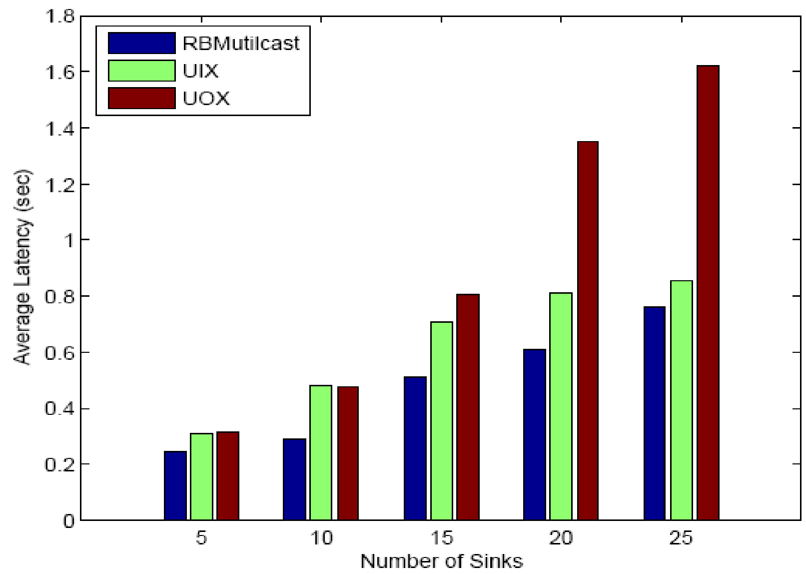


Average latency

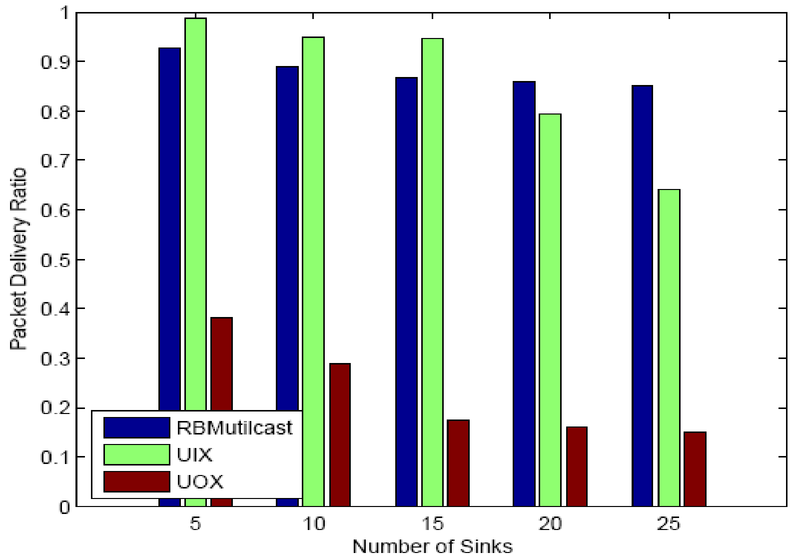


Average total traffic

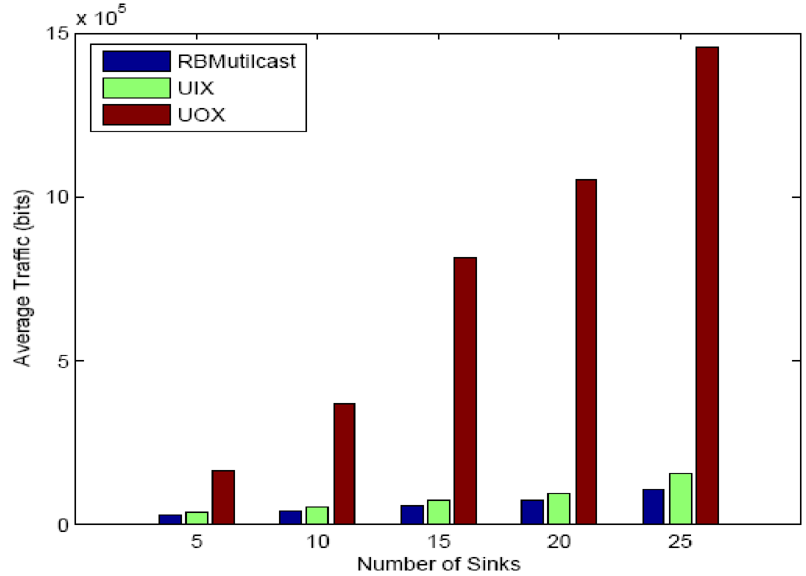
Uniform Distributed Sinks, Mobile Networks



Average latency



Packet delivery ratio



Average total traffic

Conclusion

Compared with the XLM multiple unicast, simulation results show that RBMulticast achieves much better performance in terms of latency and network traffic. It is also shown that the performance of RBMulticast is closely related to the distribution to the sinks.

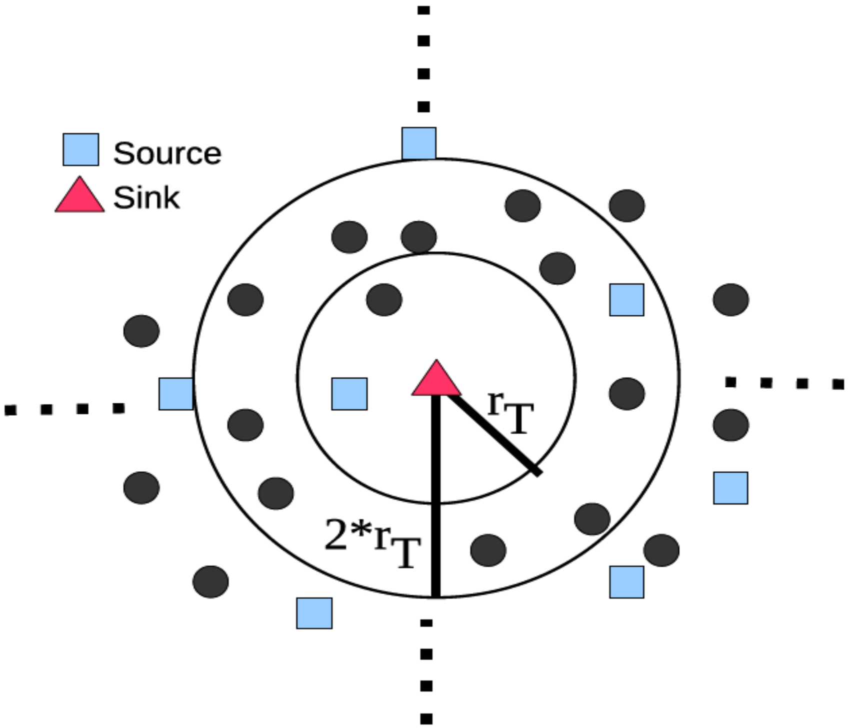
- Introduction and Background
- RBMulticast Enhancements and Performance
- Energy-efficient Duty Cycle Assignment
  - Distance-based Duty Cycle Assignment Methods (DDCA)
  - Traffic-Adaptive Distance-based Duty Cycle Assignment Methods (TDDCA)
  - Performance Evaluation
- Future Work

Motivation

- Few previous researches focused on the energy efficiency for convergecast.
- In convergecast, the duty cycles of the nodes should be adjusted appropriately to ensure energy efficiency while meeting traffic demands.
- The traffic relayed at a node is related to its distance to the sink.
- DDCA: Given the distance from a node to the sink, the duty cycle is derived for minimizing energy.

Traffic Rate Analysis

- Topology applied in this research:



Traffic Rate Analysis

- Approximated Model:

$$\lambda_r = \frac{\lambda_g \rho_s \pi \left\{ R^2 - [(\lceil \frac{r}{r_T} \rceil - 1) r_T]^2 \right\}}{\rho_r \pi \left\{ [(\lceil \frac{r}{r_T} \rceil) r_T]^2 - [(\lceil \frac{r}{r_T} \rceil - 1) r_T]^2 \right\}}.$$

Where r_T is the transmission range, λ_g is the average traffic generation rate of the source nodes, ρ_s is the density of the source nodes. R is the radius of the network area, ρ_r is the density of nodes, and λ_r is the average traffic rate of a node at distance r to the sink.

- Establish the relationship between the node's traffic and its distance to the sink.

Duty Cycle for a Given Expected Traffic Rate

- To derive the duty cycle that minimizes the energy consumption for a given traffic rate.
- The following duty cycle analysis is based on the idea that the expected energy consumption of a sensor node is proportional to the expected total awake time, t_l , and the time needed for transmission, t_t of the node.
- *N:* average number of nodes within a node's transmission range
- *d:* duty cycle,
- λ_r: average traffic rate of a node located at distance *r* to the sink node.
- T_L :the listen period at each cycle.
- ξ : the ratio of the relay region.

Duty Cycle for a Given Expected Traffic Rate

- The expected time needed before the first successful RTS/CTS handshake, t_H , is then

$$t_H = (e^{\xi dN} - 1)^{-1}(T_{RTS} + N_p N_r T_{CTS})$$

- The expected total time for a complete RTS, CTS, DATA and ACK packet communication is

$$t_C = T_{RTS} + xT_{CTS} + T_{DATA} + T_{ACK}$$

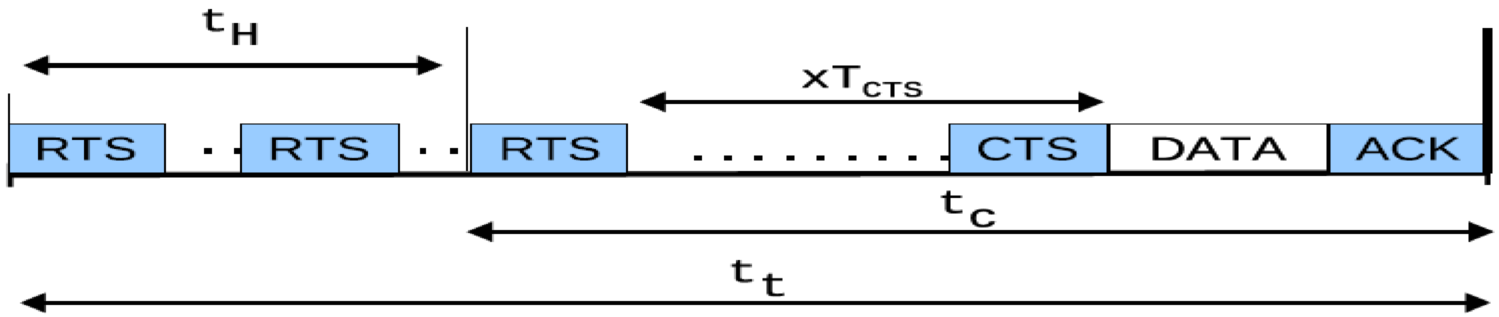
where *x* represents the number of CTS contention slots up to and including the first successful CTS packet and can be omitted for the sake of brevity.

Duty Cycle for a Given Expected Traffic Rate

- The expected total time for a node to transmit a packet, including all the failed RTS packets and the successful data exchange is

$$t_t = t_H + t_C$$

shown as follows:



Duty Cycle for a Given Expected Traffic Rate

- The average active time of a node that receives traffic and that resides in the relay region of the sender node is

$$t_1 = \tfrac{T_L}{2} + \frac{1-e^{-\xi dN}}{\xi dN} t_C + \left(1 - \frac{1-e^{-\xi dN}}{\xi dN}\right)\tfrac{T_L}{2}$$

- The expected time a node is awake during one listen period is

$$t_l = (1 - p_0\xi)T_L + p_0\xi t_1$$

- The expression for the expected energy consumption per unit time, $\bar{P}$, is

$$\begin{aligned}\bar{P} &\simeq P \times \tfrac{t_l}{T_L/d} + \lambda_r P t_t \\ &\simeq P\{d + \lambda_r[(e^{\xi dN} - 1)^{-1} N_p N_r T_{CTL} + 2T_{DATA}]\}\end{aligned}$$

Duty Cycle for a Given Expected Traffic Rate

- Take the derivative of the expected energy consumption function with respect to *d* and set it to zero to find the duty cycle that minimizes the expected energy consumption.

$$d_{opt} = \frac{\log[\frac{\alpha+2+\sqrt{\alpha(\alpha+4)}}{2}]}{\xi N}$$

where $\alpha = \lambda_r \xi N N_p N_r T_{CTS}$.

- The mathematical relation between duty cycle and average traffic rate is derived.

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Motivation

- The analysis presented considers expected traffic relayed by a node at a given distance, in practice the actual traffic loads vary per node and over time.
- The entire analysis focuses on minimizing energy consumption while leaving the end-to-end delay performance as a later concern.
- The analysis does not take packet contention and collision into consideration.
- TDDCA: Combine the analysis in DDCA and the real traffic pattern.

Inspiration

- The number of retransmitted RTS packets reflect the traffic pattern.
- A piggyback flag is introduced to the packet header of the RTS packet to indicate whether this packet is being retransmitted or not.
- A counter is also set in every node to record the numbers of the initial and retransmitted RTS packets.

Traffic-Adaptive Distance-based Duty Cycle Assignment (TDDCA)

- When receiving an RTS packet, node examine whether it is in the sender's forwarding zone (relay region)
  - If yes and the total number of the received retransmitted RTS packets in the current cycle outnumbers the total number of the received initial RTS packets, the duty cycle of the node is increased.
  - Otherwise, the duty cycle of the node is decreased down to a minimal 1% to minimize the energy consumption.

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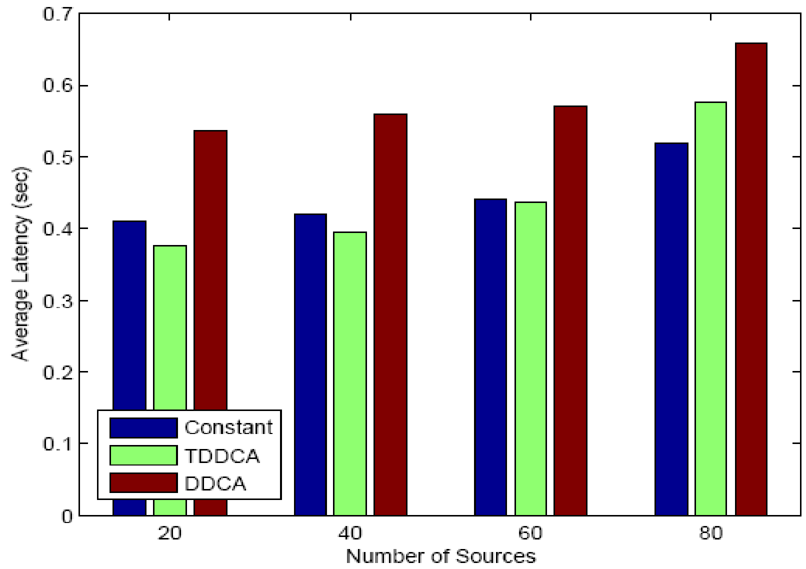
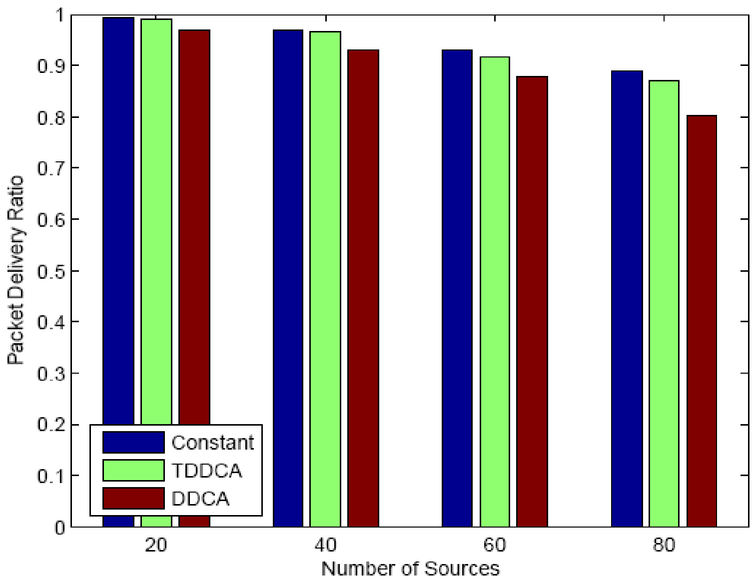
- R = 90m
- r_T = 30m.
- P = 1.
- 400 nodes
- In TDDCA, the duty cycle is changed by 1% every listening interval.
- The simulation performed: varying number of sources
- The network-wide constant duty cycle assignment method is compared with. This duty cycle is set to the duty cycle found by the DDCA method for the nodes one hop away from the sink, such that a high packet delivery ratio is guaranteed.

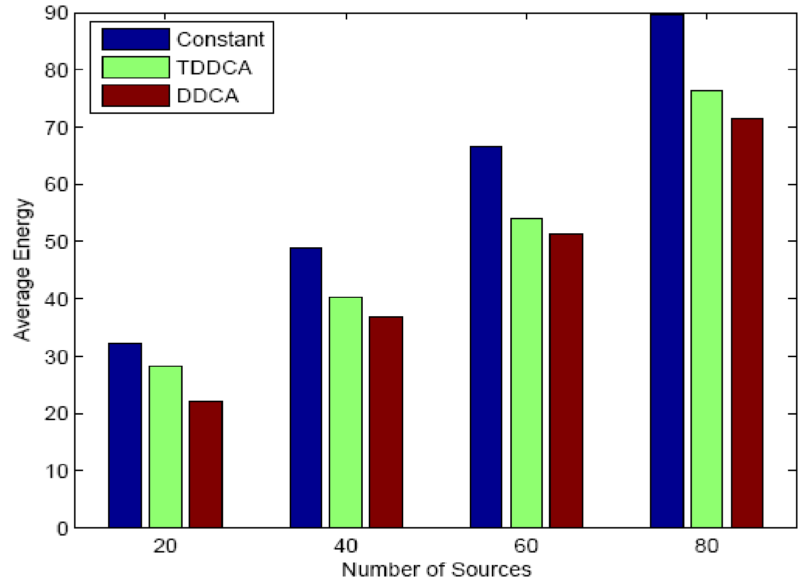
Varying Number of Sources



Average latency



Packet delivery ratio



Average energy

Conclusion

- Simulation results show that both methods decrease energy consumption compared with the constant duty cycle method for the scenarios investigated. The TDDCA assignment method achieves energy improvements without sacrificing from the latency and throughput significantly.

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Future Work

- Generally, RBMulticast performs better when sinks cluster than when they are sparsely distributed. Therefore, RBMulticast can be extended to improve performance when sinks are sparsely distributed.
- DDCA and TDDCA show a better performance in low and medium traffic than in high traffic. Analysis can be extended to improve the performance of distance-based duty cycle assignment in heavy traffic scenarios, by taking packet collisions and contention into account.

Thank you!