Encounter-based Message Broadcasting in Ad Hoc Networks with Intermittent Connectivity

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Motivation

•Majority of related work on randomized mobility models in ad hoc networks includes simplifying assumptions:

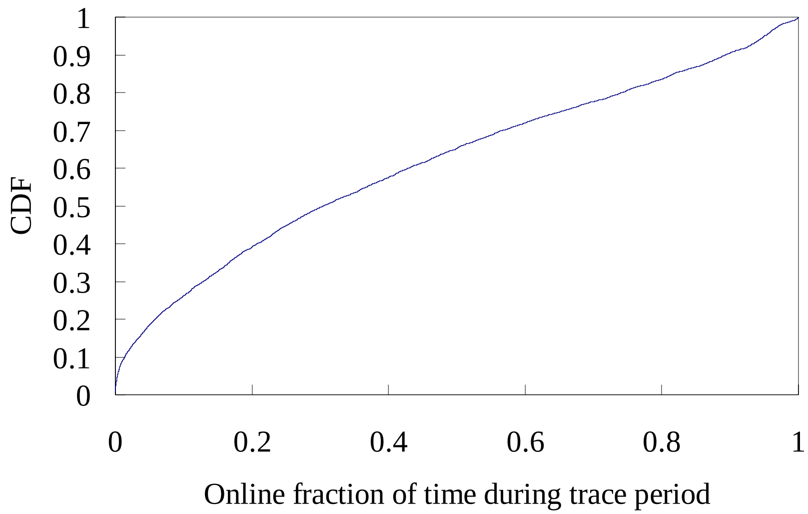
	Typical work on ad hoc networks	Generic user behaviors (our assumption)
Device usage	Always on	On-off pattern
Device mobility	Based on simple synthetic models, usually the same for all nodes	Depends on the nature of individual user
Temporal correlation	No temporal correlation between movement decisions of the same user	Patterns depending on daily schedule/ preference of user
Cross-user correlation	Users make independent movement/usage decisions	Users have correlated behaviors

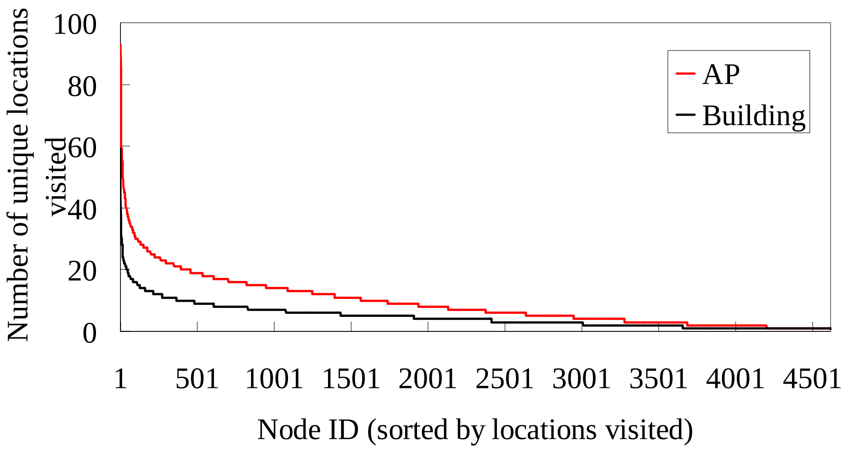
•In this work we take association patterns of a wireless network [1] and use it as an empirical model for an ad hoc network.

•Objective: Evaluate the potential of encounter-based forwarding mechanism under empirical network trace-based model.

The trace-based model

- We use a 802.11 wireless network trace [1] as a usage model for wireless users. The users are only on when they are observed in the trace.
- The empirical model for wireless users shows:
  - On-off usage pattern, about 60% of users are online for less than 50% of time during trace period.
  - Small number of locations visited by each user, among 623 APs all users visited less than 100 among them. Similarly for buildings.





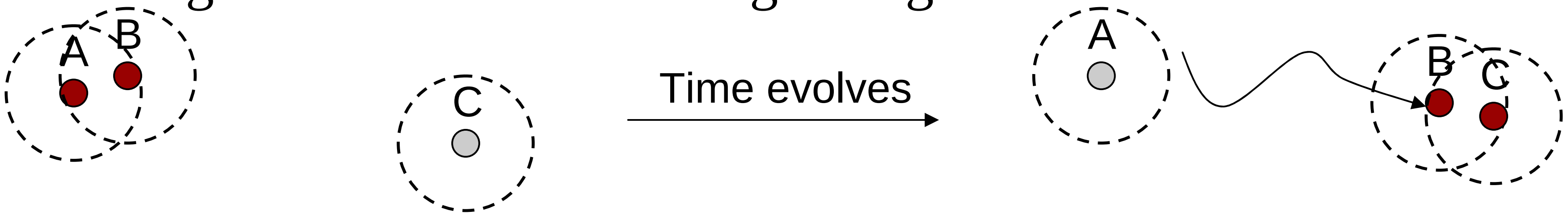
- Path-based packet forwarding (e.g. DSR, AODV) would not work well if nodes are not always on

Encounter-based delay tolerant network (DTN) approach

•Network partition (due to on-off usage pattern, mobility, etc.) is normal network dynamics rather than abnormality.

•Packets are sent from the sender without knowing full path leading to the receiver. The intermediate nodes store the packets temporarily and forward it later.

•In DTN paradigm packets are disseminated through node mobility and pair-wise encounters followed by packet exchanges between nodes during a longer time frame.



Facts about the empirical model

Number of users	Duration of trace	Number of APs	Number of buildings
4618	Mar. 1 – Mar. 15 2004	623	184

Encounters of nodes in the empirical model
~ Do we have enough encounters to form a network?

•Define *encounter* as 2 nodes online at the same AP or building.

•Define *encounter relation graph*: A link between 2 nodes is added to the graph if the two nodes have at least one encounter during the trace period.

•The encounter relation graph is a SmallWorld [2][3] graph. It is likely we can rely on nodal encounters to deliver delay tolerant messages.

Graph type	Regular graph	Trace-based	Random graph
Clustering coefficient (AP)	0.7459	0.4293	0.0401
Clustering coefficient (Bldg)	0.7486	0.6176	0.1201
Average path length (AP)	12.5157	2.3291	1.6167
Average path length (Bldg)	4.1634	2.0037	1.3355

*From the trace, with AP-level encounters the largest connected part of the graph contains 4586 nodes, and average node degree is 183.21. With building-level encounters the corresponding numbers are 4613 and 553.62. The regular graph and random graph used for comparison are based on the same number of nodes and node degree.

Broadcast messages in the network

- Mechanisms to forward a broadcast message in the network:

(1) Repeated flooding in space domain only Source node keeps flooding the message at fixed time intervals (every 2 hours) through spatially-connected part of network if it is online. The message is delivered to spatially connected nodes only at the time it is transmitted from the source

(2) Delay-tolerant, encounter-based mechanism Source node forwards copies of the message to all nodes it encounters, and all these nodes cooperate to forward the message further when they encounter with other nodes who have not received the message yet. The definition of encounter could be:

(a) Two nodes are online under the same AP.
(b) Two nodes are online in the same building.
(c) Two nodes are online under APs within communication range (200 meters)

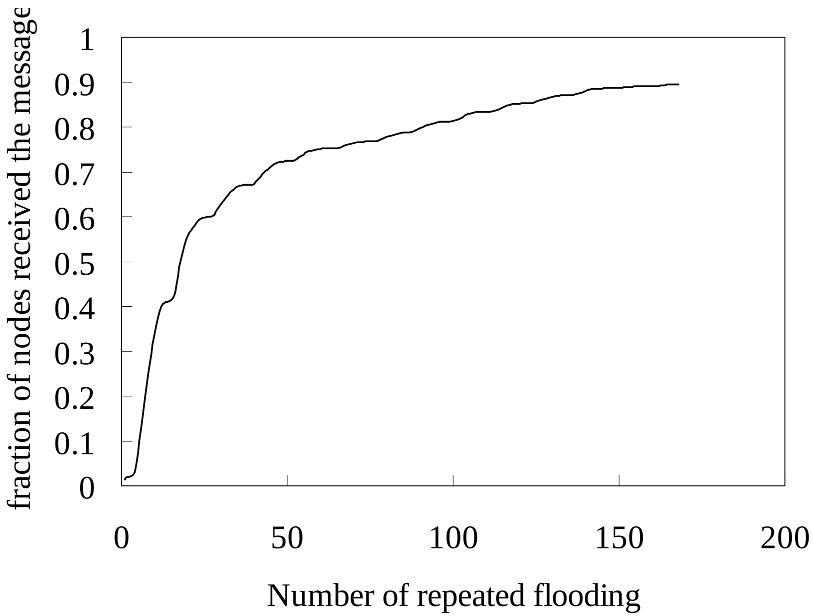
- Simulation results by choosing 500 nodes as sources, each sending one message:

Forwarding mechanism	Percentage of messages received per node	Normalized Overhead*
Repeated flooding	89.56%	44.50
Encounter-based (AP)	98.74%	3.87
Encounter-based (building)	99.56%	2.63
Encounter-based (comm. range)	99.75%	1.00

* Overhead is accounted by total transmission counts, normalized by the tx count of the forwarding mechanism with least overhead, 4485040.

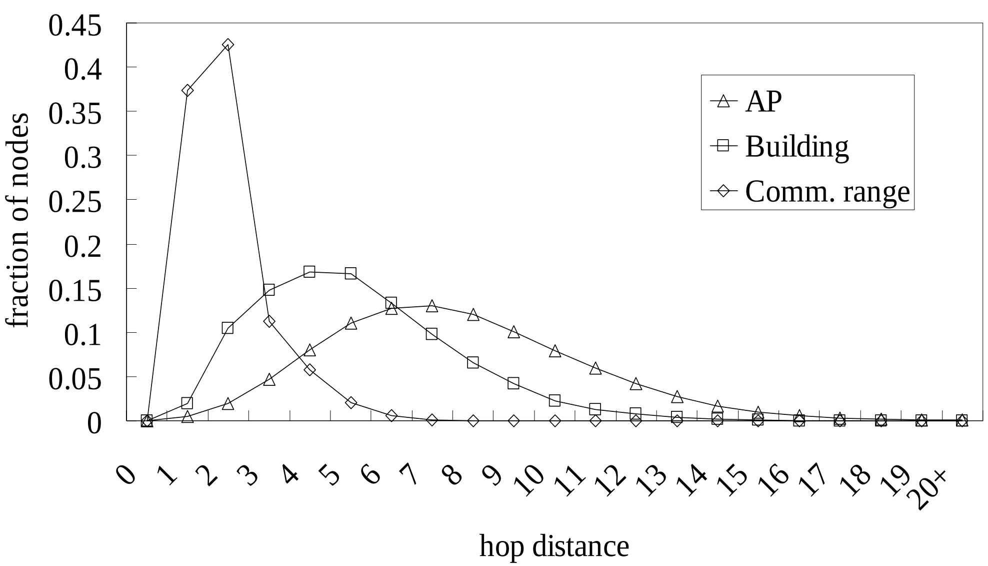
Performance evaluation

- Repeated flooding has diminishing return (number of nodes reached per additional flooding).



- Flooding in space domain fails to reach the nodes that are not online at the the times when flooding takes place.

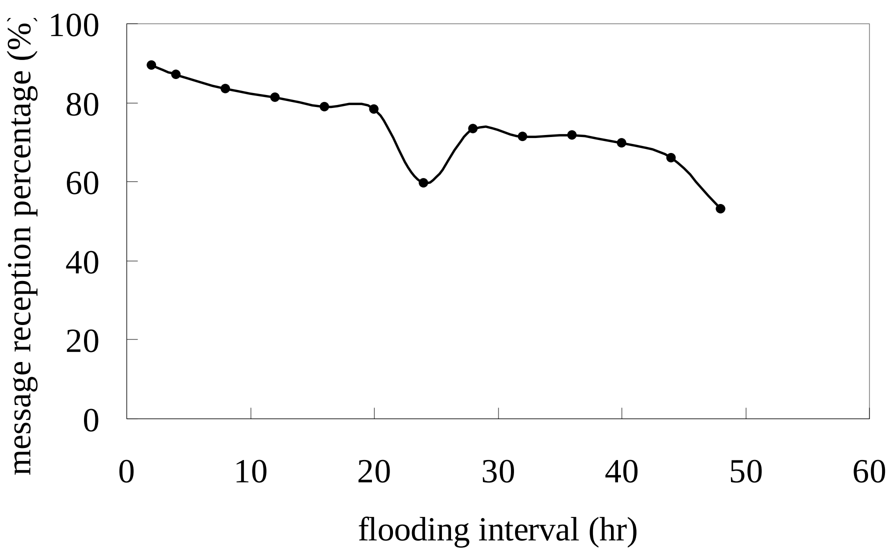
- Encounter-based schemes tend to deliver messages with high success rate (*unreachable* nodes are few).

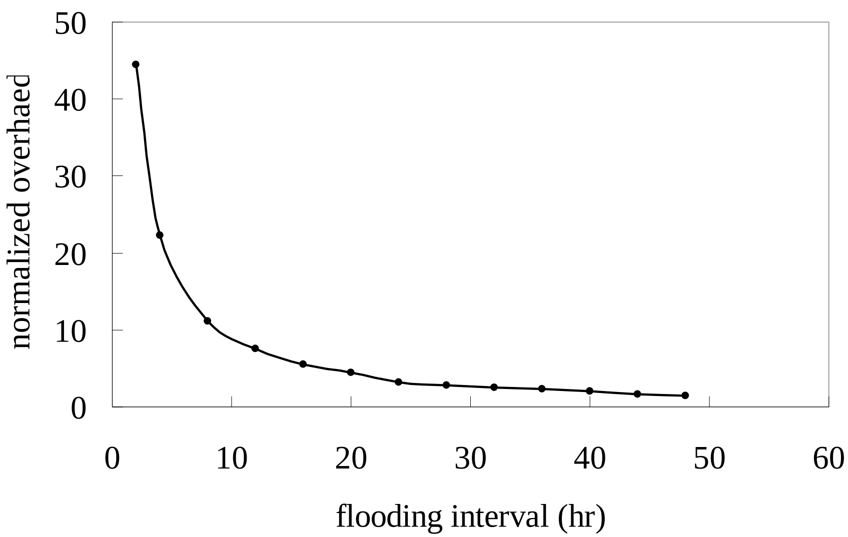


- As range of encounter increases, (AP->building->comm. range) the average hops for delivered packets decrease.

Flooding interval v.s. performance

- As flooding interval increases, the message reception percentage decreases and overhead also decreases.
- If the flooding interval is close to multiples of 24 hours, the performance shows extra dip as the trace starts by 0:00 AM. (Flooding at midnight is less effective)

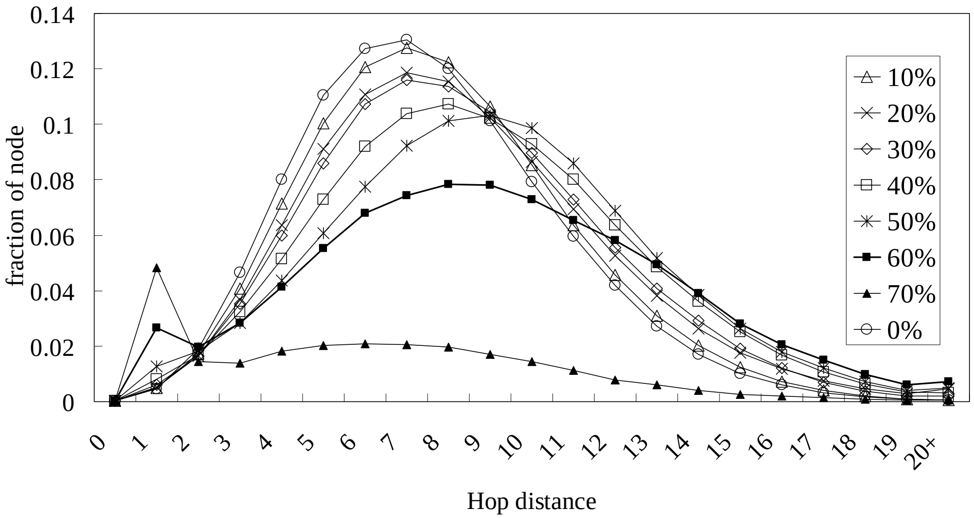


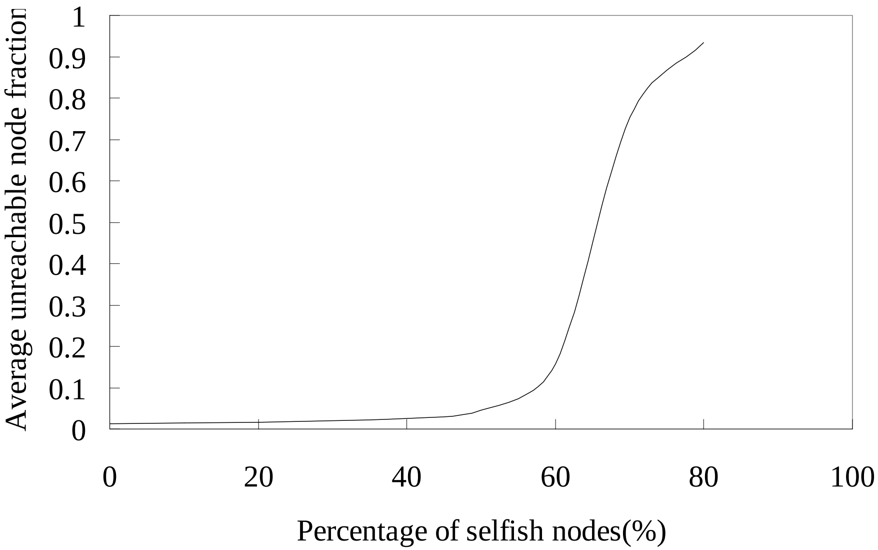


* Overhead is accounted by total transmission counts, normalized by the tx count of the forwarding mechanism with least overhead (encounter-based with comm. range, 4485040).

Robustness of encounter-based forwarding to selfish users

- Even if some nodes are selfish and do not forward messages for others, messages are still delivered using alternative path.
- The "unreachable node" for each sender increases slowly and the average path length distribution from the source to receivers shifts to longer paths until approximately 50% of nodes are selfish. After that unreachable nodes increases sharply.
- Robustness to node removal is a typical property of SmallWorld graphs.





Conclusion

- Under trace-based models of wireless network users, we illustrate how it is possible to utilize nodal encounters alone to forward messages to reach majority of users in the network.
- Encounter-based forwarding is robust to selfish user behavior.

Future Work

- We plan to study node encounter patterns, create a model for it, and design more intelligent message forwarding mechanisms.
- We plan to investigate the generality of the SmallWorld model using traces from USC and other campuses over extended durations.
- Establish the relationship between raw node mobility and network usage model.

References

[1] T. Henderson, D. Kotz and I. Abyzov, “The Changing Usage of a Mature Campus-wide Wireless Network,” in *Proceedings of ACM MobiCom 2004*.

[2] D. J. Watts and S. H. Strogatz. "Collective Dynamics of 'Small-World' Networks," *Nature*, vol. 393, pp. 440-442, 1998.

[3] A. Helmy, "Small Worlds in Wireless Networks," *IEEE Communications Letters*, pp. 490-492, Vol. 7, No. 10, October 2003.