A Flooding Protocol for MANETs with Self-Pruning and Prioritized Retransmissions

Prioritized Flooding with Self-Pruning (PFS)

Martin Jacobsson, Cheng Guo and Ignas Niemegeers
TU Delft, The Netherlands

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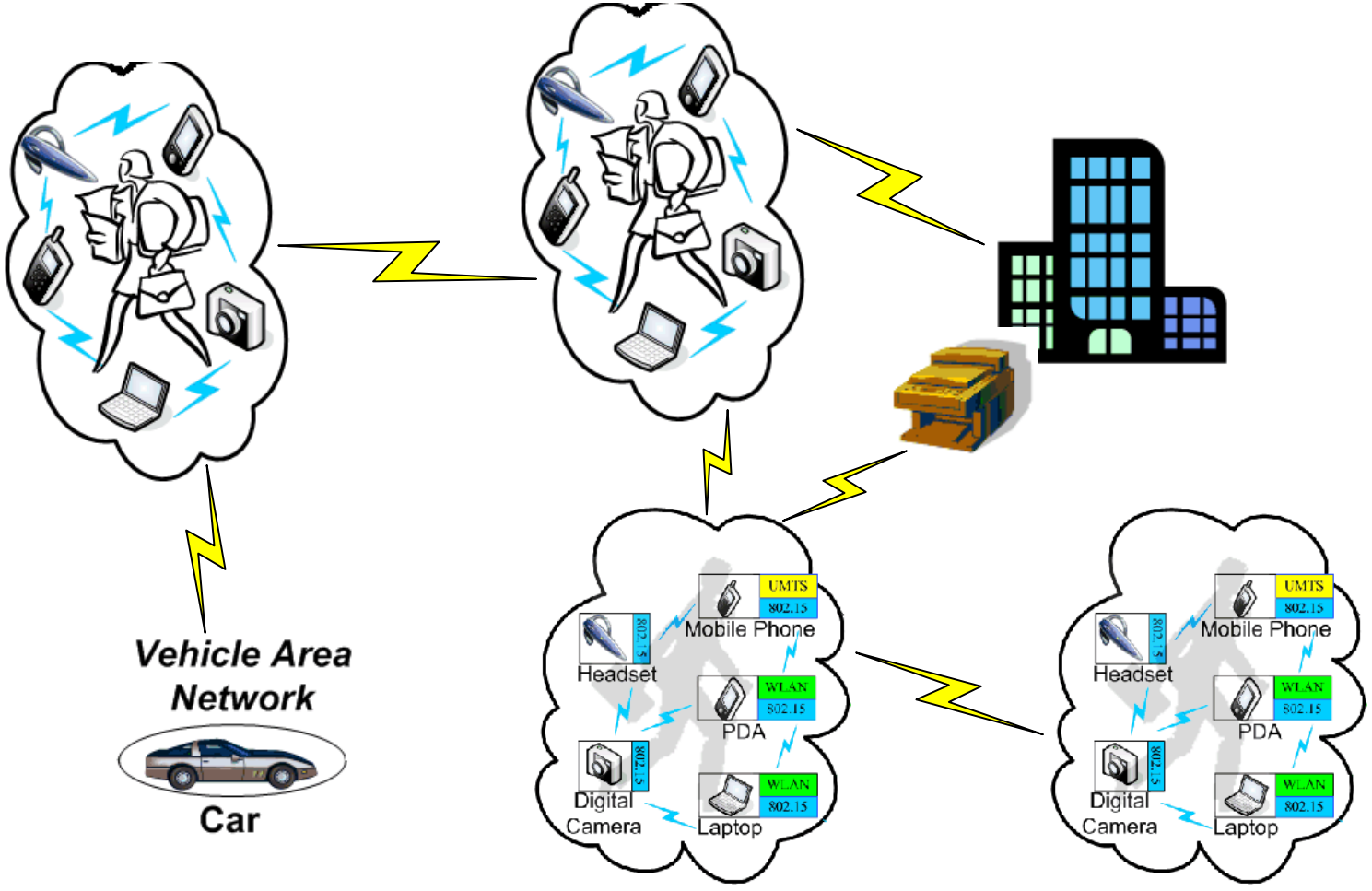
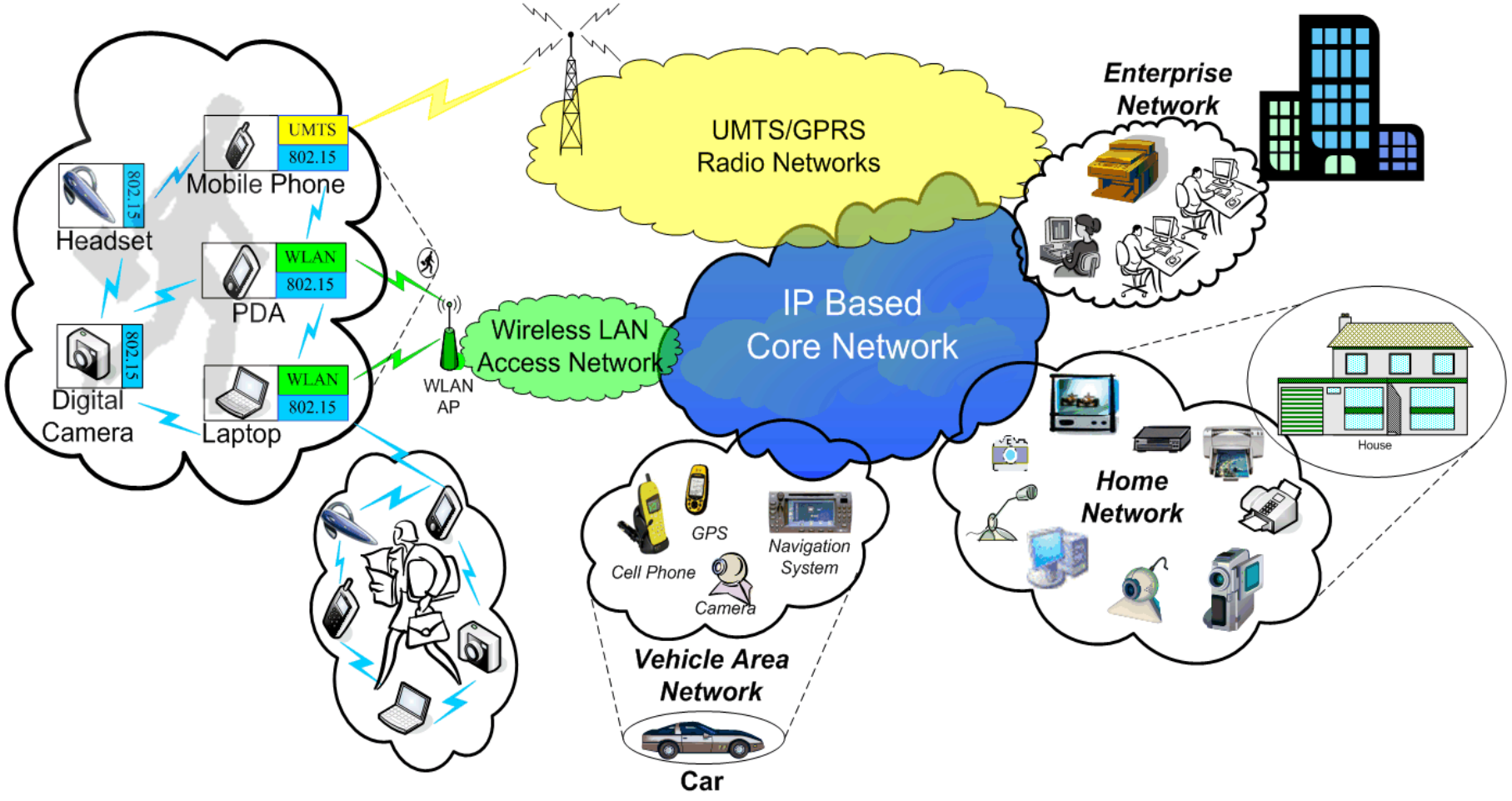
The Outline of this Presentation

- Introduction
- Motivations, objectives and assumptions
- Some existing MANET flooding protocols
- Prioritized Flooding with Self-Pruning: PFS
- Simulation set up and results
- Conclusions and future work

Mobile Ad Hoc Networks: MANETs



Personal Networks



Flooding in Mobile Ad Hoc Networks

- Flooding is a network-wide broadcasting by which a packet is disseminated to all other nodes with some nodes acting as relays.

- The most used flooding protocol in MANETs is Blind-Flooding. All nodes always retransmit each received flooding packet to all nodes in its transmission range.

- The only optimization is that each node remembers the flooding messages it received and does not retransmit them again when duplicates are received.

Motivations

- Flooding is a fundamental operation in MANETs and extensively used by routing, multi-cast tree construction, leader election, service discovery, context discovery, automatic addressing, and more...
- "AODV's routing load is dominated by route request packets (often as much as 90%)"

  Charles E. Perkins et al, "Performance Comparison of Two On Demand Routing Protocols for ad hoc networks", *IEEE INFOCOM 2000.*
- However, Blind-Flooding has problems:
  - Causes a lot of unnecessary overhead
  - Causes collisions, which leads to poor reachability
  - Causes contention, which leads to poor performance

Assumptions

- All nodes in a network share a common wireless channel.
- All nodes have the same transmission range. Bi-directional links are assumed.
- All nodes are unaware of their geographic locations, no positioning devices, such as GPS.

Some Existing Flooding Protocols

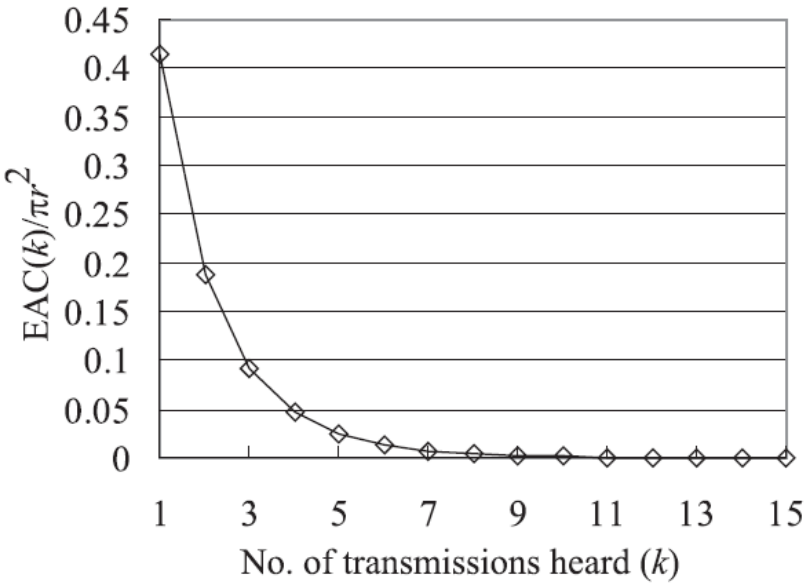
- Blind-Flooding, used in AODV and DSR
- Counter-Based Broadcasting (CBB)

Neighbor knowledge-based protocols:

- Flooding with Self-Pruning (FSP)
- Scalable Broadcasting Algorithm (SBA)
- Multi-Point Relay Flooding (MPR), used in OLSR
- Ad Hoc Broadcasting Protocol (AHBP)

Counter-Based Broadcasting (CBB) - 1

If several nodes randomly distributed around a source node send out the same flooding message, the Expected Additional Coverage, EAC(k) after the node heard the message k times is:



From: Yu-Chee Tseng, Sze-Yao Ni, Yuh-Shyan Chen, Jang-Ping Sheu, The broadcast storm problem in mobile ad hoc networks, Wireless Networks, Volume 8, Issue 2/3, Pages 153-167, Kluwer Academic Publishers, May 2002.

Counter-Based Broadcasting (CBB) - 2

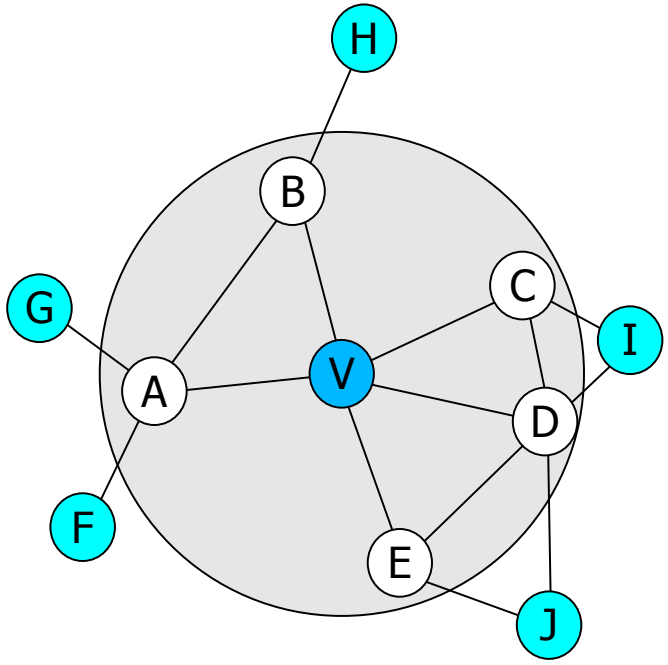
- Upon receiving a flooding message for the first time:
  - Schedules a retransmission after a Random Assessment Delay (RAD) between 0 and T_{MAX}
  - Initialize a counter k to 1
- Upon receiving a duplicate flooding message:
  - Increase k by 1
- When the RAD expires:
  - If the counter k is less than a threshold, then retransmit
  - Otherwise, cancel the retransmission
- The threshold should be around 3

Scalable Broadcasting Algorithm (SBA)

- SBA is a neighbor knowledge-based flooding protocol:
  - It collects information about its neighbors and their neighbors by using two-hop hello messages.
- SBA uses **self-pruning** to avoid unnecessary retransmissions:
  - A node monitors who else is retransmitting the same message.
  - By using the collected two-hop neighbor information it knows if all neighbors have been covered by other's retransmissions. If so, it cancels the retransmission.
- The retransmission delay (RAD) is random but influenced by the number of neighbors.

Ad Hoc Broadcasting Protocol (AHBP)

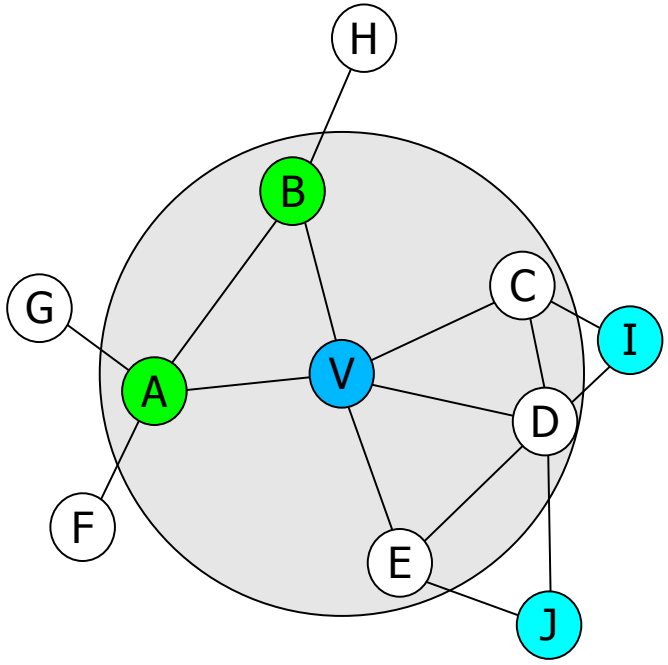
- AHBP also requires two-hop hello messages:
  - one-hop neighbor set: N(v)
  - two-hop neighbor set: $N^2(v)$
- Each node selects a set of its one-hop neighbors as BRG(v) (Broadcasting Relay Gateway) to cover all its two-hop neighbors.
- The BRG list is included in the flooding message header.



Ad Hoc Broadcasting Protocol (AHBP)

Step 1

- Add one-hop neighbor u to BRG(v), if there is a node in $N^2(v)$ only covered by u.
- Any node in $N^2(v)$ that is not covered by BRG(v) is called an uncovered node.



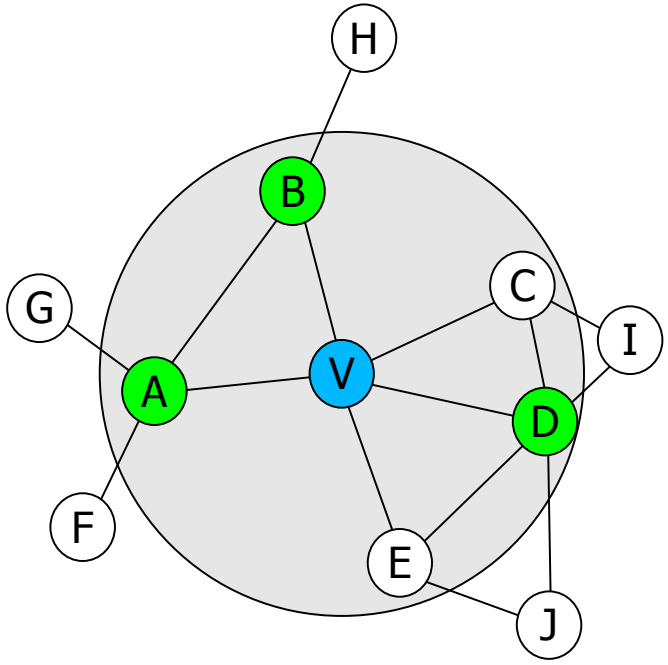
Ad Hoc Broadcasting Protocol (AHBP)

Step 2

- Add one-hop neighbor u to BRG(v), if node u covers the largest number of uncovered nodes in $N^2(v)$.

Step 3

- Repeat step 2 until there is no uncovered node in $N^2(v)$.

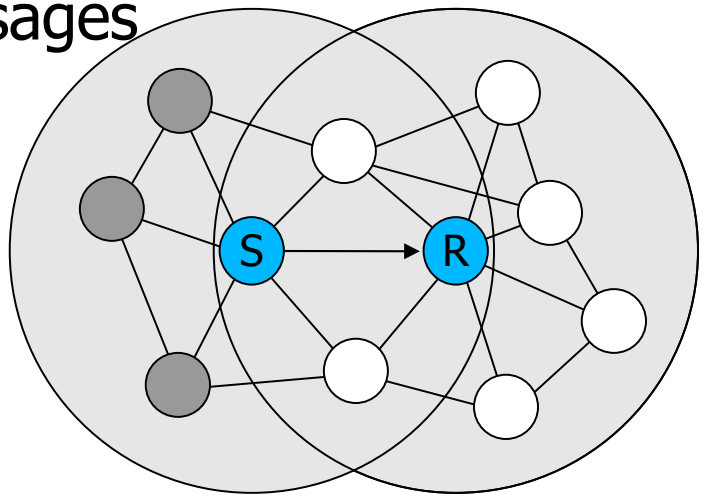


Prioritized Flooding with Self-Pruning

- Prioritized Flooding with Self-pruning (PFS) is similar to SBA.
- PFS has the following characteristics:
  - One-hop hello messages only
  - Self-pruning
  - Strict order of retransmissions based on number of uncovered neighbors
- All this will be explained shortly...

PFS Uses One-Hop Hello Messages

- PFS only requires one-hop hello messages
  - They are small
  - They may already be required by other protocols
  - Many Data Link Layer protocols provide them
- Each node encloses its one-hop neighbor list in the flooding messages

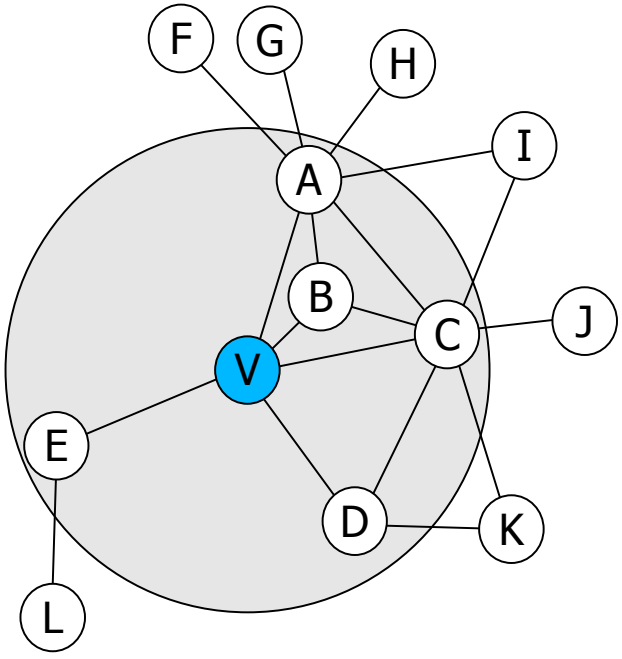


The Basic Idea Behind PFS

- Self-Pruning:
  - Upon receiving a new flooding message, the node schedules to retransmit the message after a RAD and records its neighbors covered by the sender.
  - Upon receiving duplicate flooding messages, the node also records the neighbors covered by the sender.
  - If all its one-hop neighbors are covered, it cancels the retransmission, otherwise it retransmits the message when the RAD expires.
- Priority of retransmissions:
  - Nodes with more uncovered neighbors retransmit earlier.

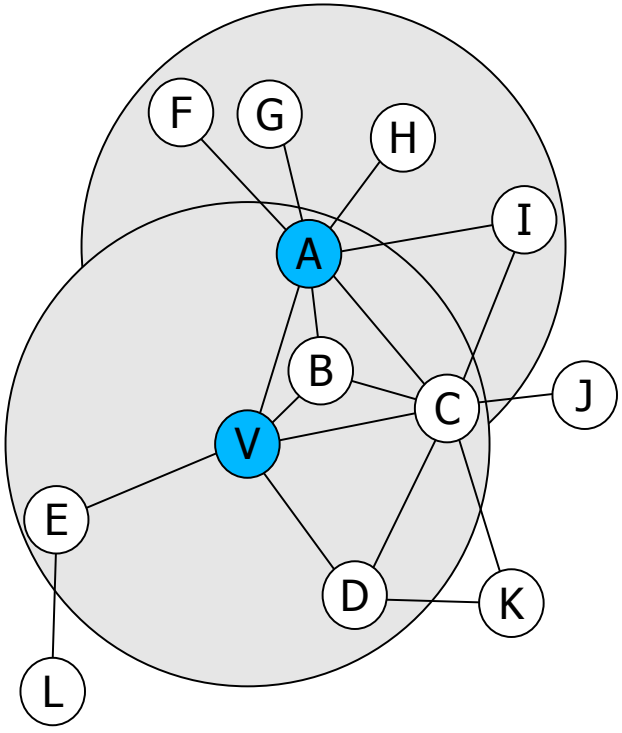
Prioritize the Retransmissions (1)

Node	Neighbours	Uncovered Neighbours	Order
V	A,B,C,D,E	-	0
A	V,B,C,F,G,H,I	F,G,H,I	1
B	V,A,C	Ø	-
C	V,A,B,D,I,J,K	I,J,K	2
D	V,C,K	K	3
E	V,L	L	3



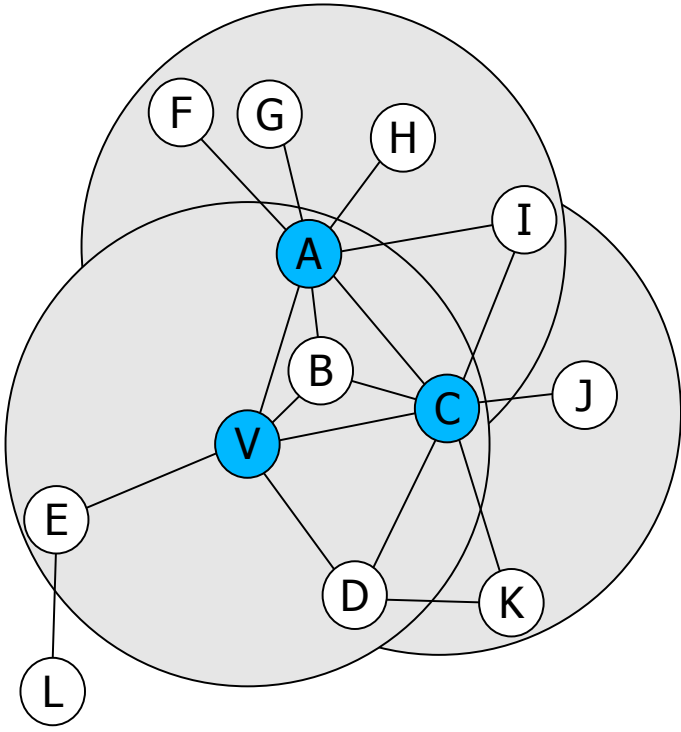
Prioritize the Retransmissions (2)

Node	Neighbours	Uncovered Neighbours	Order
V	A,B,C,D,E	-	0
A	V,B,C,F,G,H,I	Ø	1
B	V,A,C	Ø	-
C	V,A,B,D,I,J,K	J,K	2
D	V,C,K	K	3
E	V,L	L	3



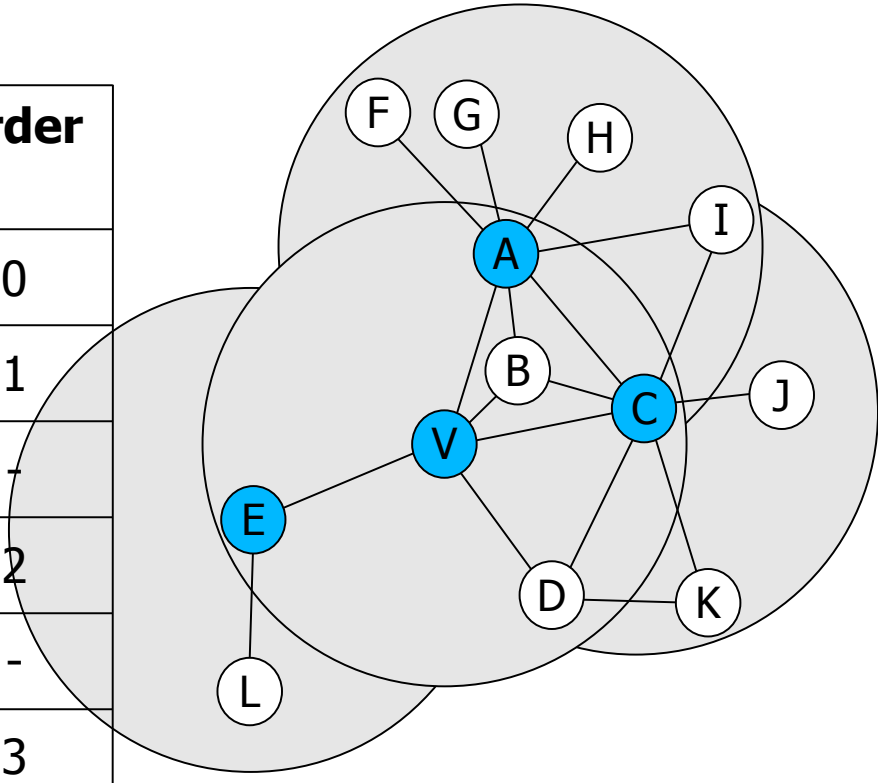
Prioritize the Retransmissions (3)

Node	Neighbours	Uncovered Neighbours	Order
V	A,B,C,D,E	-	0
A	V,B,C,F,G,H,I	Ø	1
B	V,A,C	Ø	-
C	V,A,B,D,I,J,K	Ø	2
D	V,C,K	Ø	-
E	V,L	L	3



Prioritize the Retransmissions (4)

Node	Neighbours	Uncovered Neighbours	Order
V	A,B,C,D,E	-	0
A	V,B,C,F,G,H,I	Ø	1
B	V,A,C	Ø	-
C	V,A,B,D,I,J,K	Ø	2
D	V,C,K	Ø	-
E	V,L	Ø	3



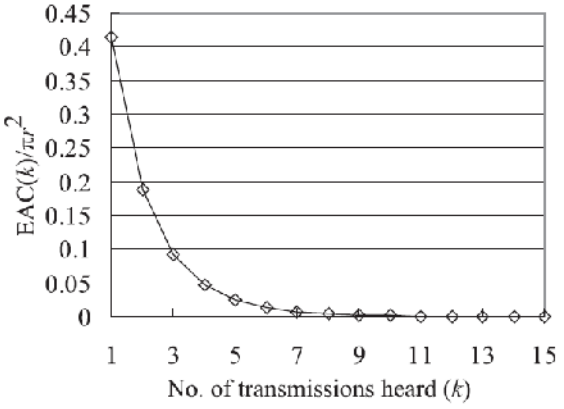
...and his process will be repeated at each receiving node.

Design of the Random Access Delay (1)

- How to determine the order?
  - The sending node does not know the "number of uncovered neighbors" of each receiving node.
  - The receiving nodes do not know the "number of uncovered neighbors" of the other receiving nodes.
- How to determine the delay?
  - The number of receiving nodes with at least one uncovered neighbor is unknown.
  - The maximum "number of uncovered neighbors" a receiving node has is unknown.
- The solution: **Estimation!**

Design of the Random Access Delay (2)

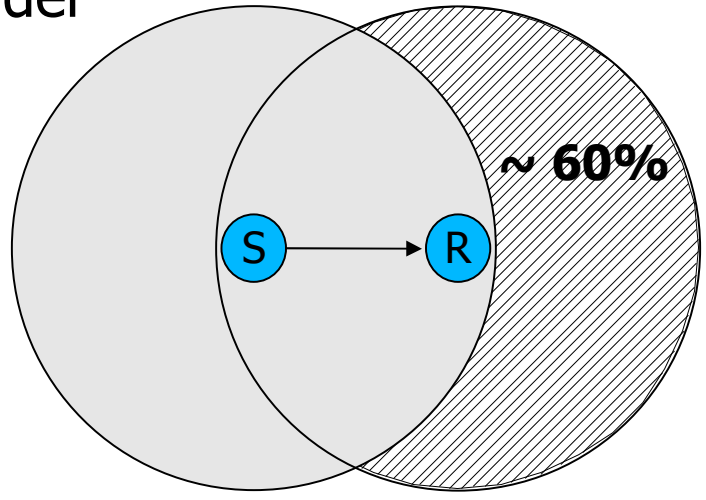
- Estimate the RAD length:
  - No more than four retransmissions are necessary (CBB result)
  - PFS will choose its retransmitting nodes in smart way => even less retransmitting nodes may be required.

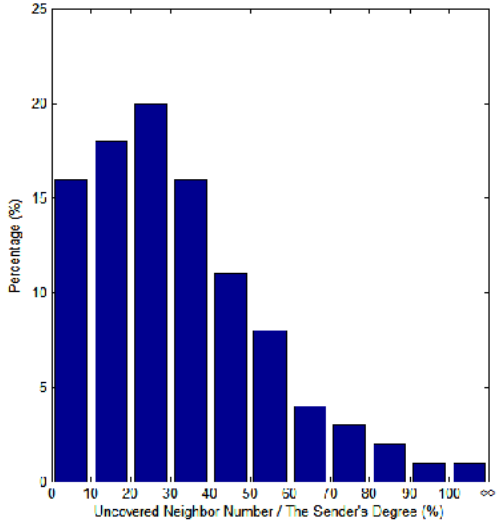


- The maximum RAD length is fixed in PFS:
  - Time needed for **5** retransmissions, including back off etc.
  - Plus some extra space for concurrent traffic
- In sparse networks, the RAD is shorter.

Design of the Random Access Delay (3)

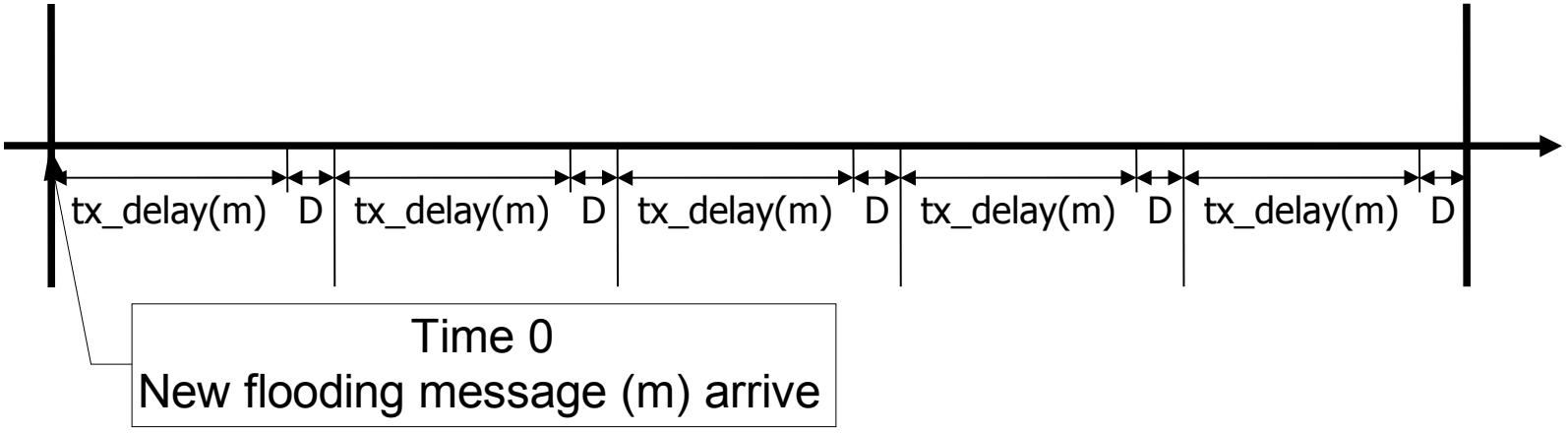
- Estimate the maximum number of uncovered neighbors
  - Assume evenly distributed nodes.
  - The (number of) neighbors of the sender is known from the flooding message.
  - The estimation is: 60% of the number of neighbors of the sender





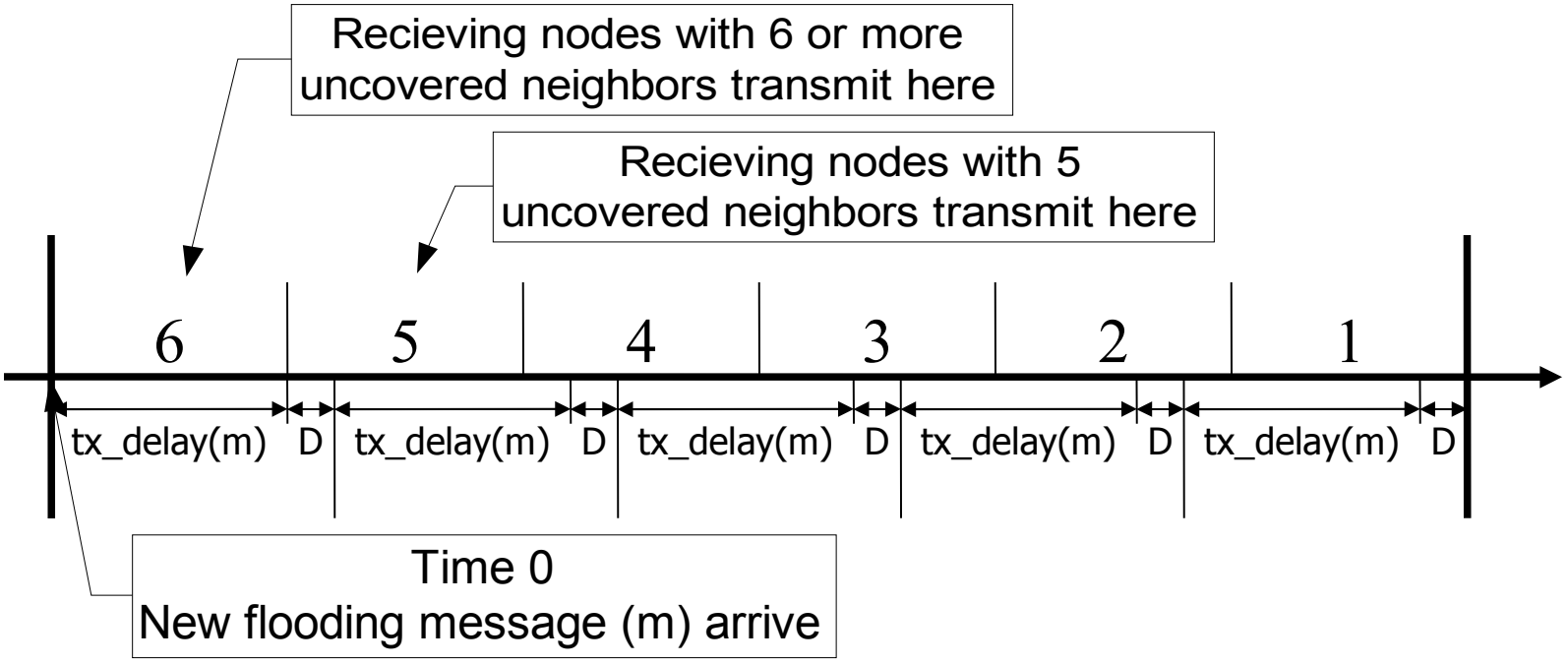
Design of the Random Access Delay (4)

- The RAD length is 5 * (tx_delay(m) + D)
  - tx_delay(m) is calculated based on message length, transmission speed, back off times, etc.
  - D is a fixed constant



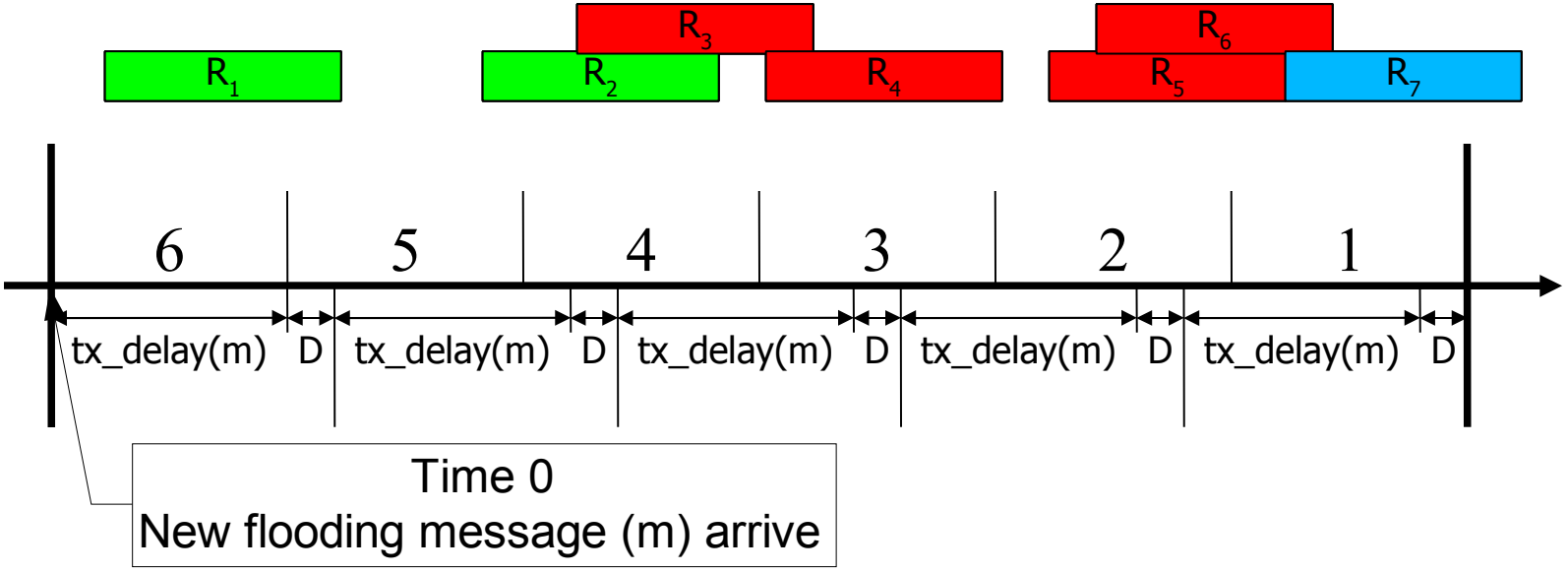
Design of the Random Access Delay (4)

- The sender has 10 neighbors
- The estimated maximum number of uncovered neighbors is therefore 6



Design of the Random Access Delay (4)

- When a node transmits, some other nodes will self-prune and cancel their retransmissions



Interface Queue Delay Problem

- A packet sent to the MAC layer may be delayed in the interface queue or waiting in MAC layer for a long time before finally being retransmitted.
- In the due time, the node may receive redundant flooding messages and self-prune. However, it is already too late!
- Solutions:
  - Increase the RAD length to minimize this effect. This introduces extra delay and the effect does not go away completely…
  - Delete the flooding messages from the interface queue and/or MAC layer with a special cross-layer function.

A Heavy Flooding Traffic Extension

- When the frequency of flooding messages increases, some neighbor lists enclosed in the flooding packet headers are frequently repeated.

- Possible solution:
  - Each node caches the neighbor lists of their neighbors from the flooding messages.
  - This cache is used to self-prune instead
  - The neighbor lists in the flooding messages is only included if there is a change in the sender's neighbor list

Simulation Parameters

Number of nodes	120 or 100 ~ 190
Simulation area	1000 m x 200 m
Transmission range	100 m
Transmission data rate	2 Mbit/s
Simulation time	100 s
Flooding message payload	64 bytes
Flooding rate	2 or 1 ~ 40 packet/s
Hello message frequency	1 packet/s
Random waypoint pause time	0 s
Maximum node speed	0 or 1 ~ 10 m/s
PFS delay parameter (D)	1.2 ms
CBB threshold	3

Measurements

1. **Reachability:**

   The percentage of how many nodes received the flooding message

2. **Number of Retransmissions:**

   The number of retransmissions required to flood a message

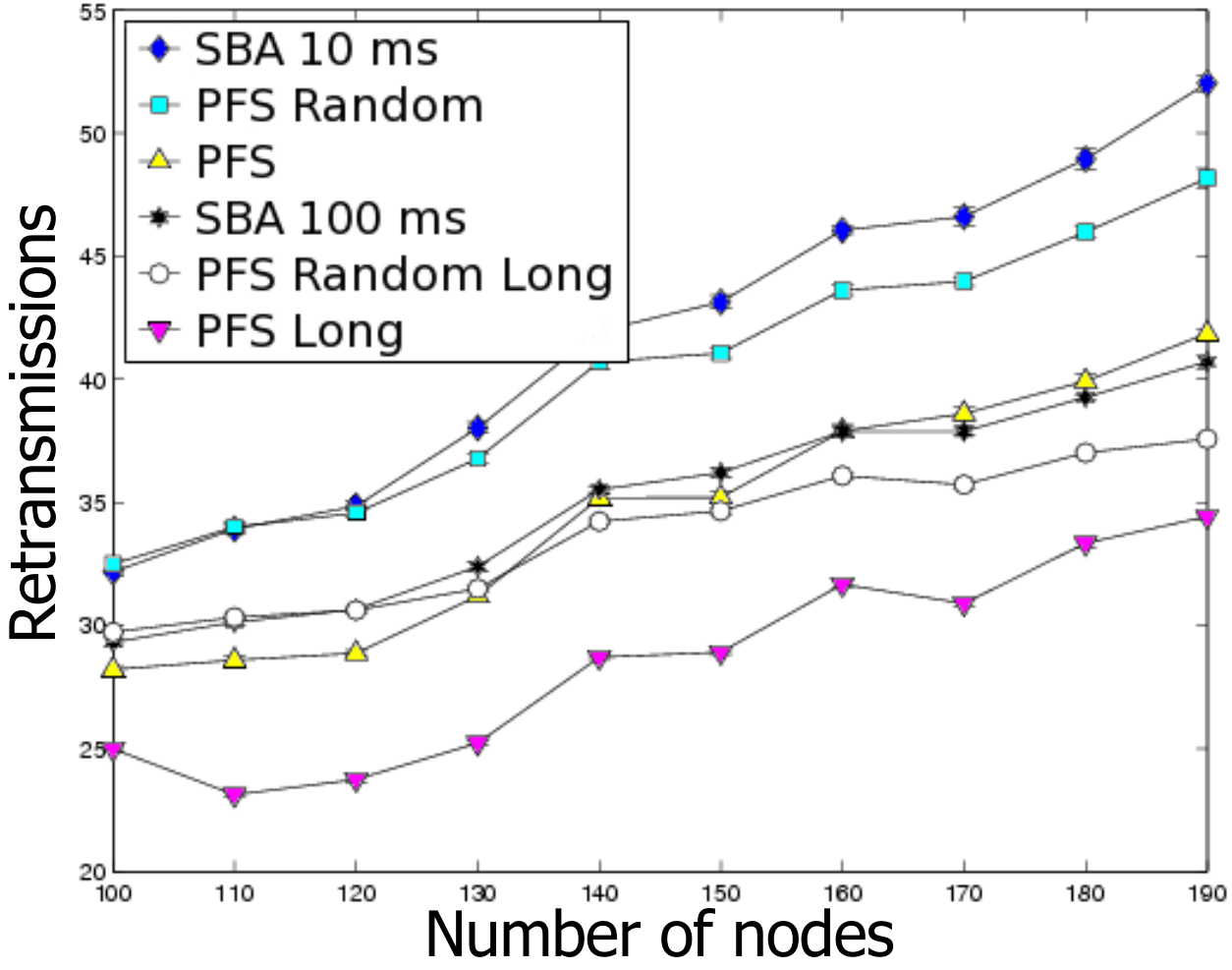
3. **Overhead:**

   How many bytes were transmitted in total to flood a message, including hello messages

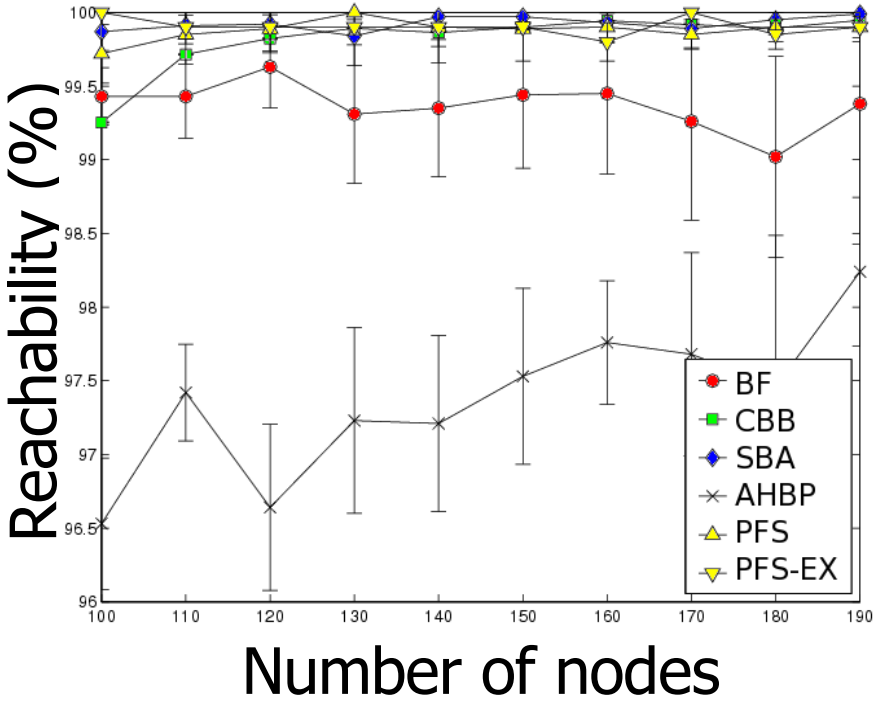
4. **End to end delay:**

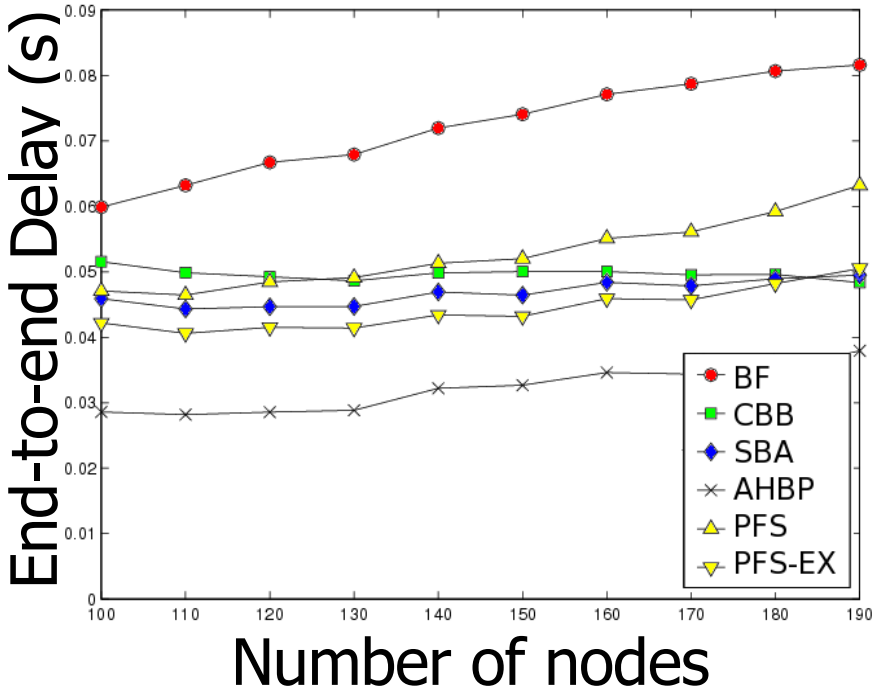
   The time interval from the moment that a flooding message is first transmitted until the moment that the last node receives the message

The Delay Factor (D)

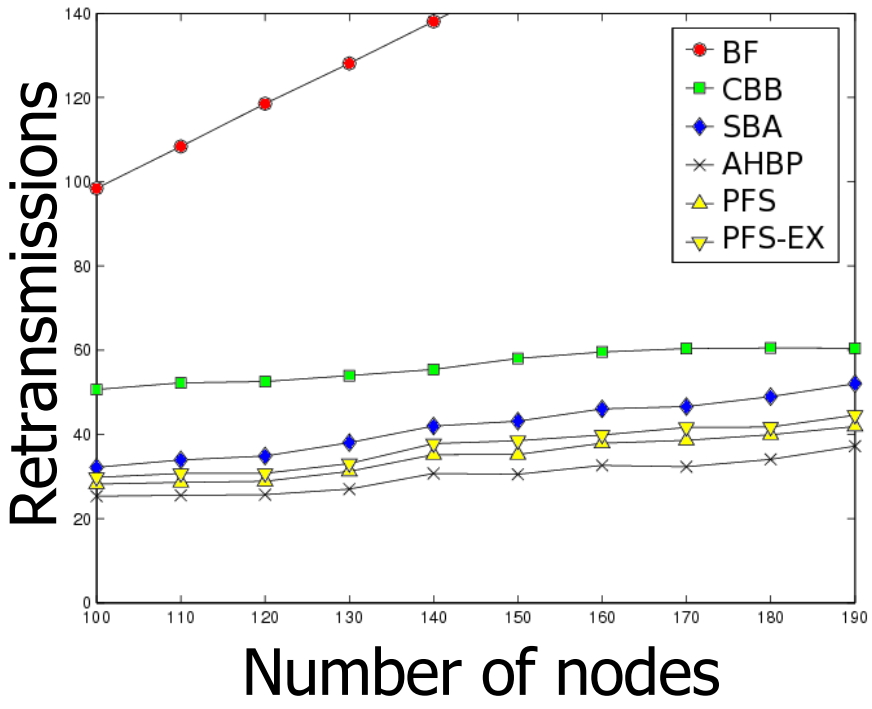


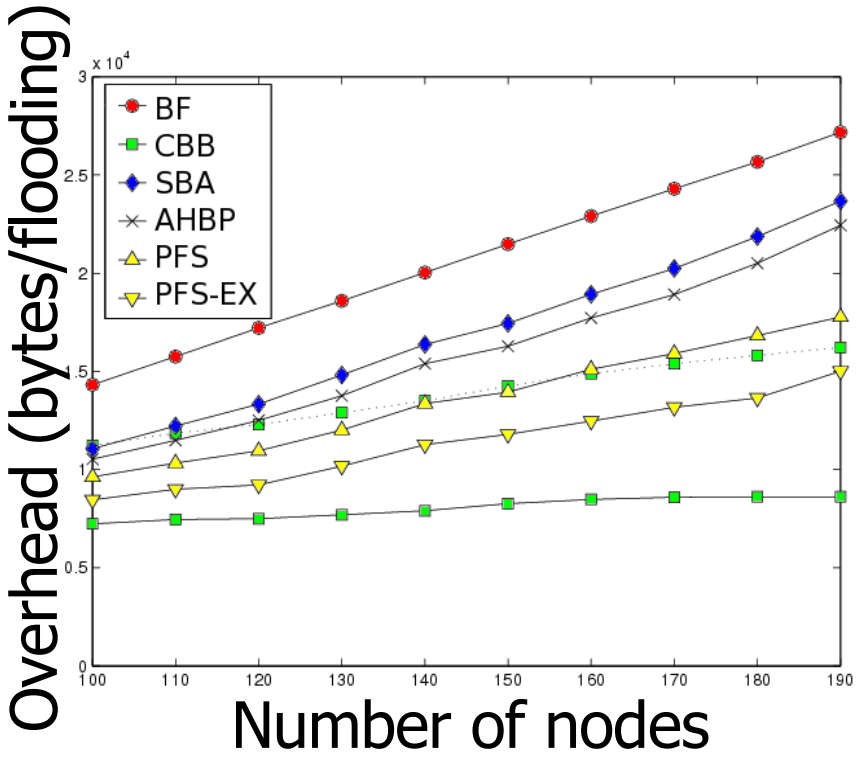
Scalability (1)





Scalability (2)





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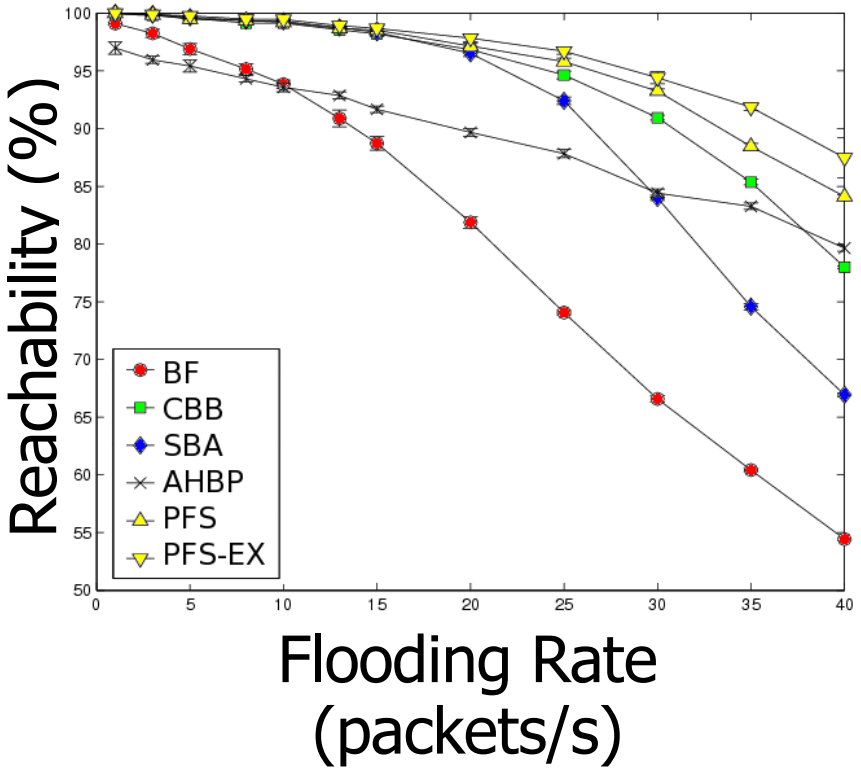
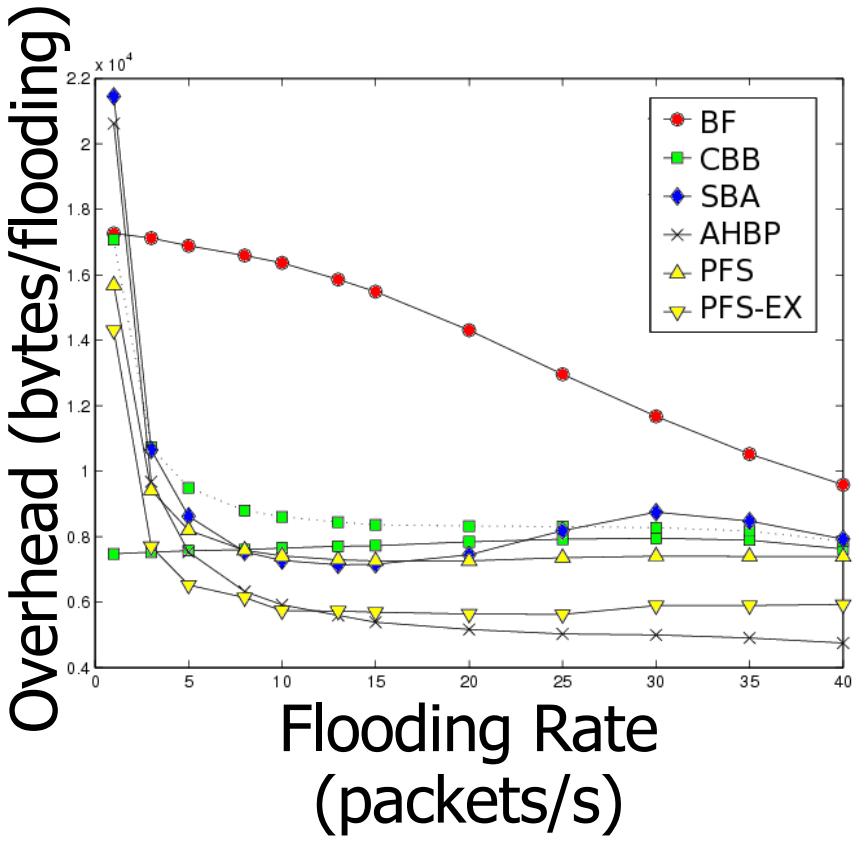
Congestion





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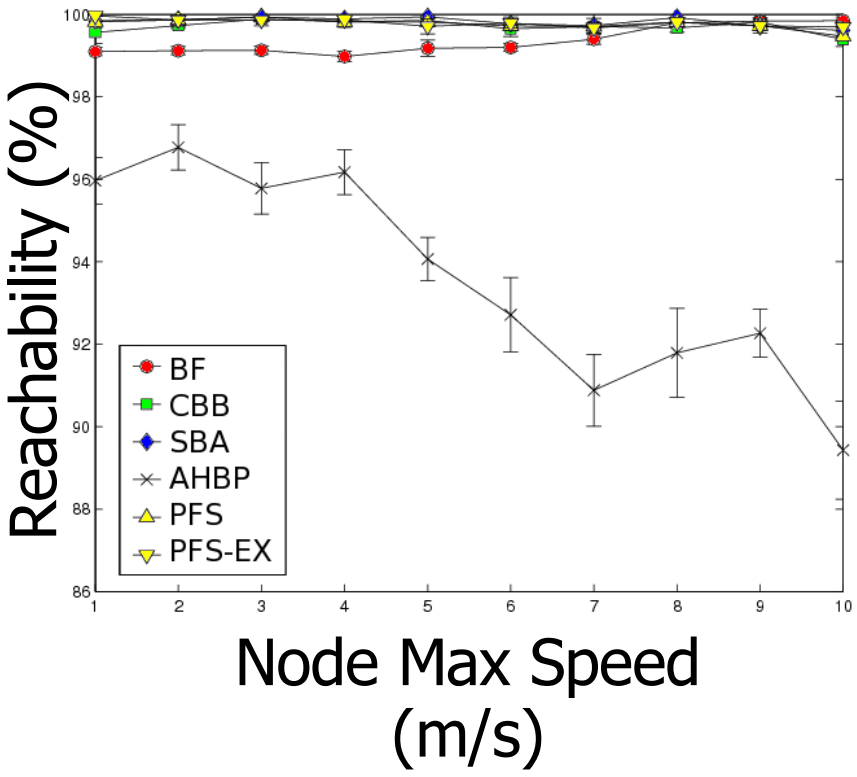

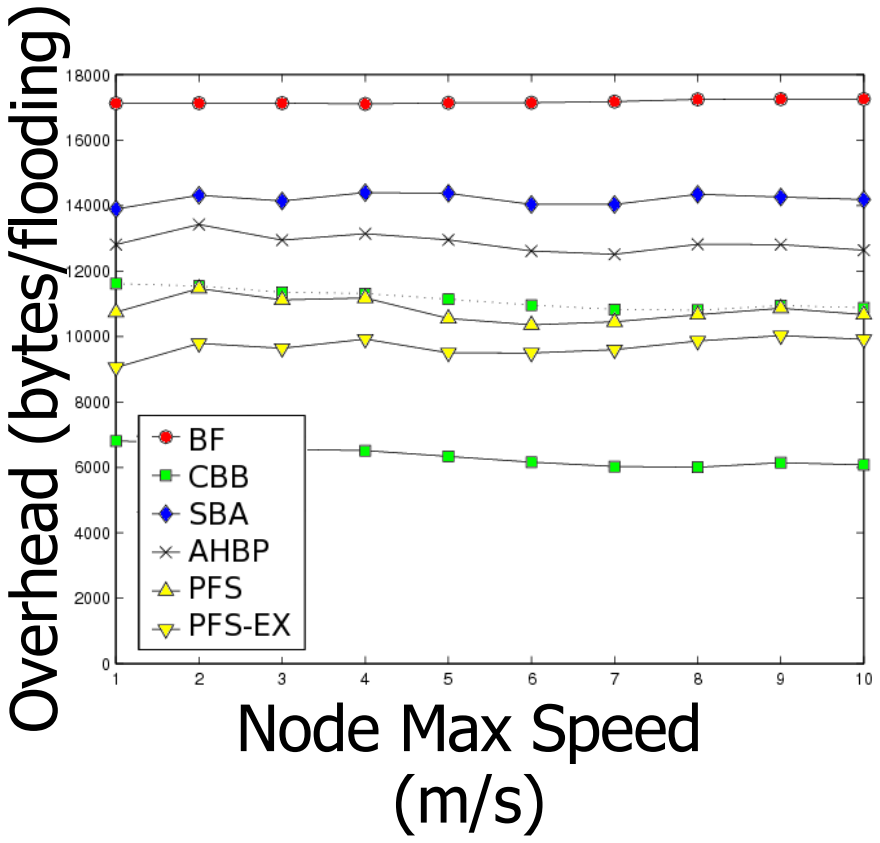

Conclusions

- We proposed a new flooding protocol for multi-hop ad hoc networks — PFS
- In comparison with existing flooding protocols, PFS:
  - copes very well with collisions
  - has a high reachability even when mobility is high
  - efficient in overhead, especially when one-hop hello messages are already provided
  - is able to finish a flooding within a relatively small end to end delay

Future Work

- Further investigate the trade-off between Overhead and end-to-end delay in PFS
- Try PFS in routing protocols, service discovery, etc
- Implement and test PFS in a real ad hoc network