Efficient multi-hop broadcasting in dense nanonetworks

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THz wireless nanonetworks

- Small communication range: ~cm
  => Need multi-hop for longer communication distances

- Nanonodes have not yet been built because of technological challenges
  => Need to develop simulation tools

- Nanodes have unusual characteristics:
  - specific modulation (TS-OOK)
  - specific collisions
  - ...

Integation of several nano-machines into a single functional entity


Complete machine of µm size
• To send bits "1" sender sends pulse, while for bits "0" a silence is used
  Pulses are very short (e.g. ~100 femtoseconds)

• Pulses from a given frame are spread over a period much bigger than the pulse duration (e.g. 1000 times longer)
  This high spreading ratio makes frames from different communication overlap

• At this scale, node positions influence the reception date
  => the propagation delay (speed of light) cannot be neglected in studies
Our problem: overcrowding

- A possibly huge number of nanonodes
- Even with very small communication range nodes can have thousands of neighbours and much more
- To transmit an information to whole network: broadcast
  - Pure flooding: all nodes repeat the message, a lot of resources are wasted
    - energy
    - channel usage
- Some technique are needed to replace the naive pure flooding approach in order to reduce the number of forwards in broadcast in THz nanonetworks
Historical solutions: Adaptive probabilistic flooding

- Use probability to broadcast a packet
- The number of forwarded message is fixed and tune the probability
- **Very simple**

\[
p = \frac{f}{n}
\]

- \( p \) the forwarding probability
- \( f \) the desired number of forward
- \( n \) the number of neighbours
- Zero memory footprint
- May cause **die out**
Historical solutions: Geoforwarding and OLSR

- No GPS => No geoforwarding
  Nodes are too small to embed GPS

- No infrastructure => No relative positioning

- No memory => No OLSR
  Too many neighbours to select precisely
  Maybe no unique IDs
Historical solutions: Adaptive counter-based schemes

- Counting the number of transmissions to take the forwarding decision

- Backoff and waiting time not appropriate
  Have to be tuned correctly

- Density in nanonetworks varies widely
  Needs to take density into account

- Backoff flooding is adaptive counter-based
Our solution: Backoff flooding

When a node receives a packet it waits for a random time and check the number of copies he receives during this time. If the number of copies is below a threshold $r$, the node forwards the packet and otherwise drops it.

- Waiting time:
  \[ \text{twait} = n \times k \times 2(T_{pkt}) \]

- $n$ the number of neighbours and $k$ is a multiplier factor discussed later.

- $2(T_{pkt})$ is the time for the furthest neighbours to receive and send back the packet.

- $r$ is the redundancy threshold: the number of copies that should be send.
Properties: Window size

- Theoretical results
- $k$ determine the number of copies received
- The number of copies seen by each node should be 5
- When $k$ becomes too small, the waiting time before transmitting is not large enough and nodes forward the message before noticing that 5 copies have already been sent

neighbours: 1150
twait: 8 nanoseconds
r: 5 (fault tolerance)
k: various values
Properties: Number of copies received

- The number of copies received is higher when simulated due to the “geographical effect.”

- Even with high waiting time, nodes receive more than r copies of the packet.

- No node received LESS than r copies of the packet.

neighbours: 1150
twait: 8 nanoseconds
r: 5 (fault tolerance)
k: various values

```
Number of copies received
```

```
Number of nodes
```

```
k = 0.05
k = 0.1
k = 0.5
k = 1
k = 5
```
Properties: Geographical effect

(a) Communication radius

T

(b) 2 copies received

R1

R2

1 copy received
no retransmission yet

(c) 1 copy received
no retransmission yet

1 copy received
no retransmission yet

(d) 2 copies received

R1

R2

R3

3 copies received

(e)
Properties: Minimum backoff probabilities

- Different node densities

- Show the probability for the minimum backoff (the first transmission) to be at $x^{th}$ percentage of the window

- The probability quickly decreases: the mean backoff is lesser than the usual window / 2

  => Because the message progresses with the minimum backoff among neighbours
Properties: Delay

- Backoff flooding induces a predictable delay
- Figures represent the probability (y axis) for the rth node to transmit its copies after the time of the x axis
- Most of the probable values are in a narrow range. And the redundancy does not affect the delay
- It is a small percentage of the total window

neighbours: 1150
twait: 8 nanoseconds
r: various values
k: 1
Properties: Reachability

- Reachability comparison between probabilistic flooding and backoff flooding

- Backoff flooding is steady and reaches the whole network even with a redundancy of 1

- The backoff flooding sends fewer packets than the probabilistic flooding to reach the whole network
Conclusion

- Backoff flooding is a **counter-based forwarding** scheme adapted to **nanonetworks**
- **Guarantees** a minimum number of forwards
- Limits the number of forwarders
- Very **high reachability**
- Takes network density into account => Needs neighbours information
- Introduces a small and predictable delay
- Does not need any location system
- No die out problem, even with low redundancy
- Future work => Sleeping node: femtoseconds cycles