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PACE

Simple Multi-hop Scheduling for Single-radio 802.11-based Stub Wireless Mesh Networks

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Outline

- Introduction
- IEEE 802.11-based Stub WMN
- Stub WMN Major Problems
- PACE
- Simulation results
- Conclusions and future work

Introduction

Internet playing central role

Ubiquitous wireless connectivity to the Internet

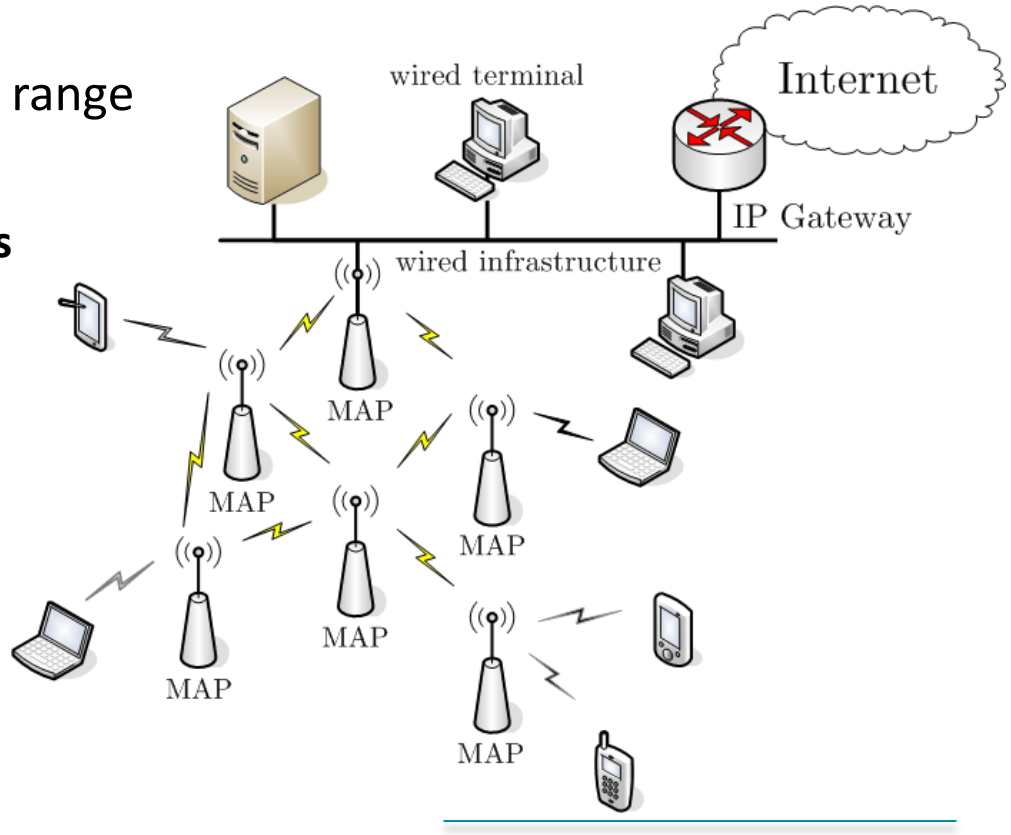
Increasing number of mobile devices	Large number of Access Points	Complex deployment	Limited wired connectivity

IEEE 802.11-based Stub Wireless Mesh Networks

IEEE 802.11-based Stub WMN

Advantages

- Compliant with legacy systems
  - **Infrastructure**
  - **STAs**
- Infrastructure extended range
- Low cost deployment
  - **Free radio frequencies**

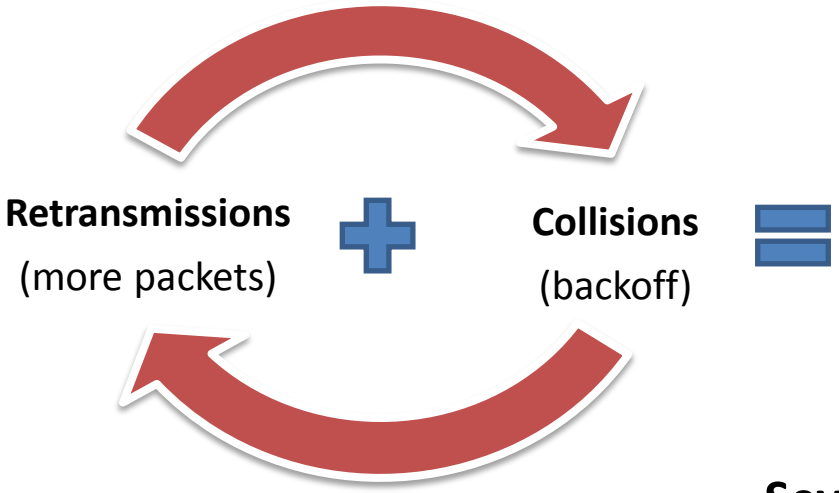


802.11-based Stub WMN – Major Problems

Inefficiency

CSMA/CA designed for single-hop networks

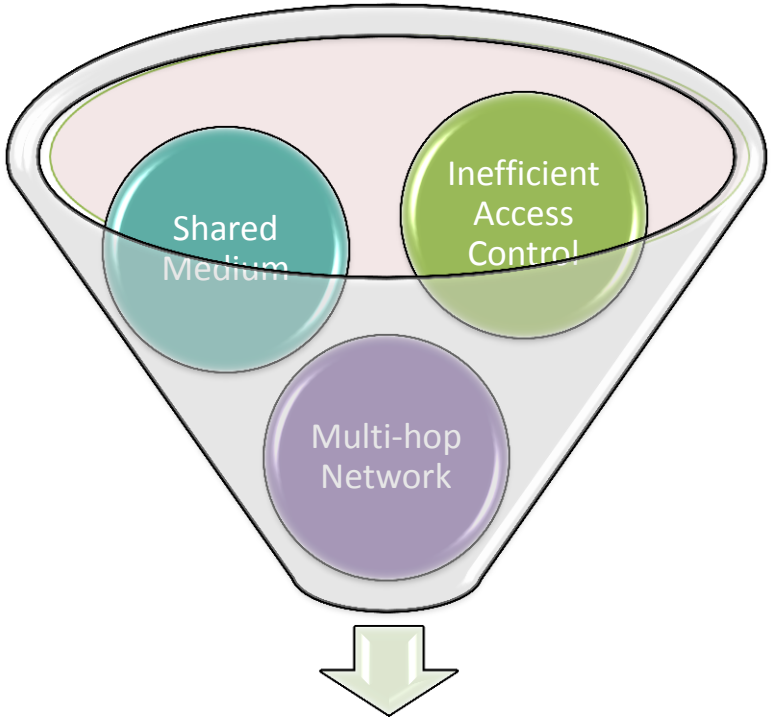
- Unable to avoid frame collisions in multi-hop networks
  - Inter/intra-flow interference (spatial contention over multiple hops)
  - Hidden/exposed node problems worsened
  - RTS/CTS harmful



- Low throughput
- High packet loss ratio
- High delay

Severe performance degradation

802.11-based Stub WMN – Major Problems



Unfairness

Nodes closer to root take control of the medium → **Node starvation**

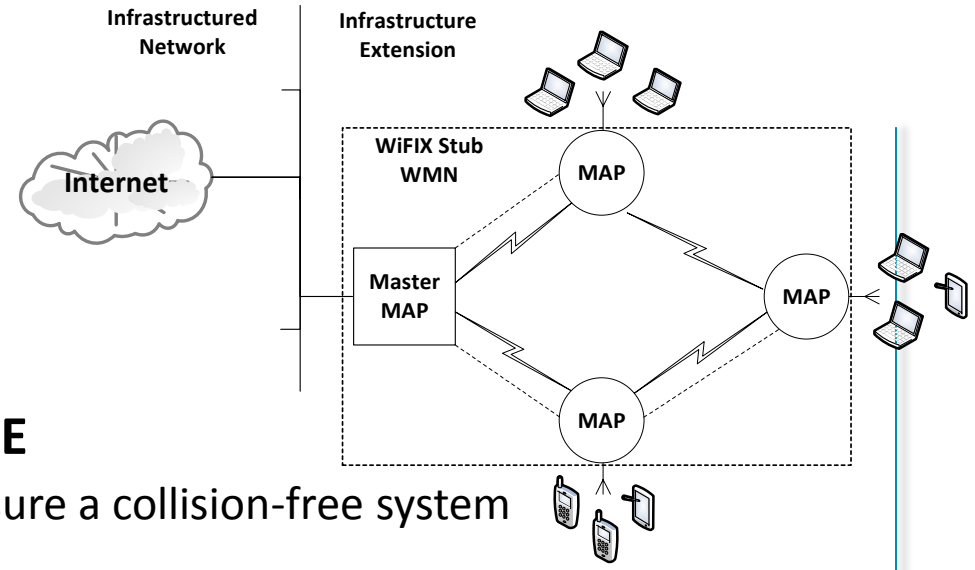
WMN – state of the art approaches

- Examples
  - RTS/CTS modifications & improvements
  - Clique techniques
  - Radio strategies
  - Spatial reuse / scheduling (NP-hard optimization problem)
- High complexity
  - Time synchronization (fixed size time slots)
  - Modifications to MAC layer
  - Higher overhead
  - Higher equipment costs
- Restrictive
  - Solve specific problems or scenarios

Simple, single-radio, 802.11-based solution is needed!

WiFIX – Wi-Fi network Infrastructure eXtension

- Tree-based routing solution for Stub WMN
- Runs on top of 802.11 MAC
- Active tree topology creation/maintenance
- Layer-2 routing based on IEEE 802.1D bridges
- Virtual Ethernet links between neighbours



Upgraded to accommodate PACE

- Routing technique updated to ensure a collision-free system
- Tweaked to improve performance

PACE – Simple Multi-hop Scheduling Mechanism

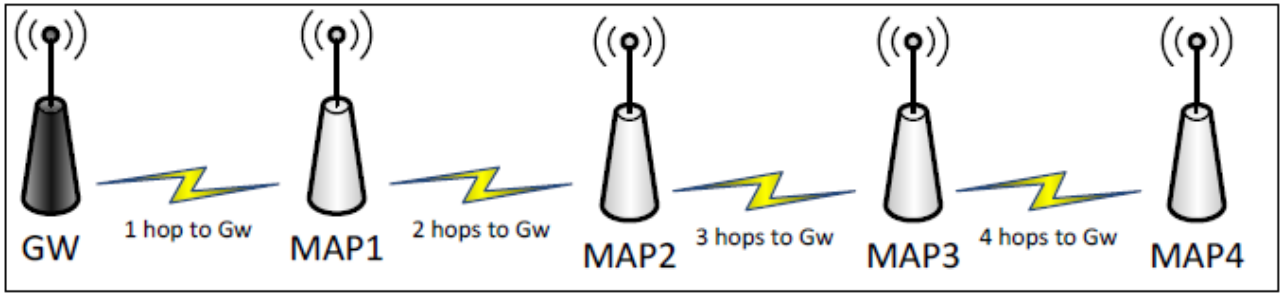
PACE – Major characteristics

- Data plane collision free operation
  - Master controls multi-hop scheduling
  - Single packet travels in Stub WMN
  - Suitable for high offered loads
- Advantages
  - Fairness between all MAPs
    - Network capacity equally divided (no spatial bias, unless enforced)
    - No starvation in MAPs far from the gateway
  - Predictable capacity
    - $C = C_{\text{Wi-Fi link}} / \text{AvgHopCount}$
  - QoS easily implementable
    - Managed by the master
- Main disadvantages
  - Exposed nodes as number of hops increases -> no spatial reuse
  - Less efficient for low offered loads

PACE – Implementation and Testing

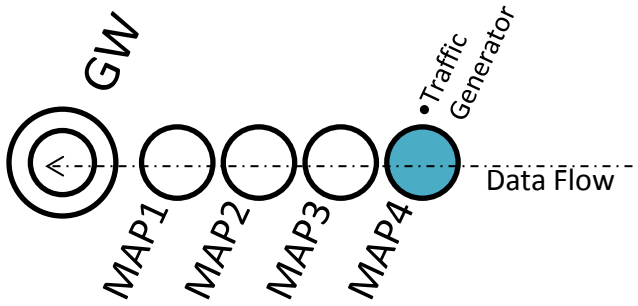
- Implemented in ns-3 NETWORK SIMULATOR
- Steps:
  1. WiFIX full implementation (with the upgrade required by PACE)
  2. PACE integration
  3. Simulation
     - i. **Fixed topology**
       - a. Chain with a gateway and 4 MAPS
       - b. 7 use cases studied
     - ii. **Random topologies**
       - a. MAPs arranged in a radial topology with the gateway at the centre
       - b. 1 use case studied
  4. Results gathered in multiple use cases
     - i. **Native CSMA/CA**
     - ii. **PACE**

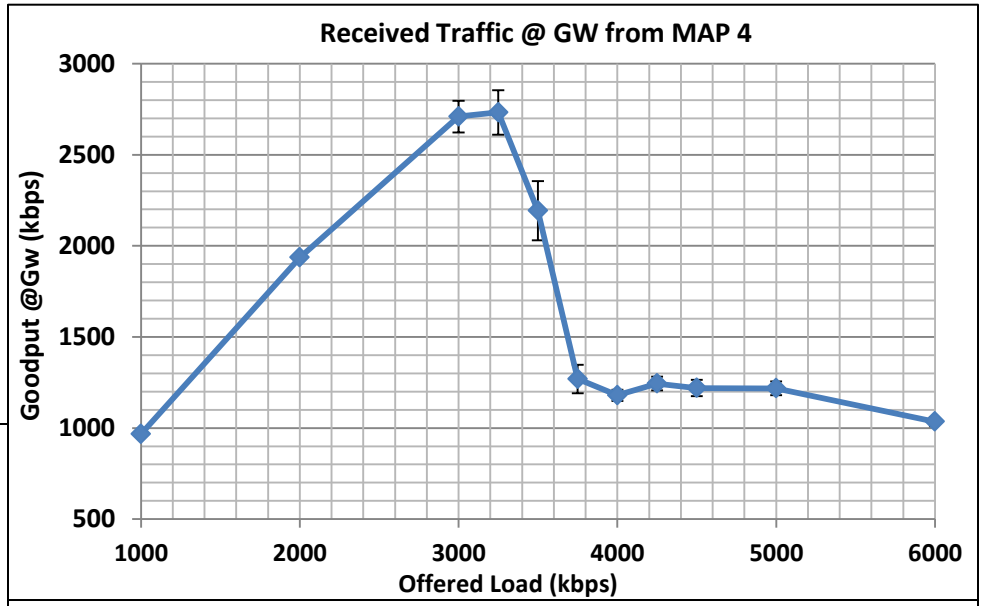
Scenario 1 – Fixed Topology | 7 Use cases

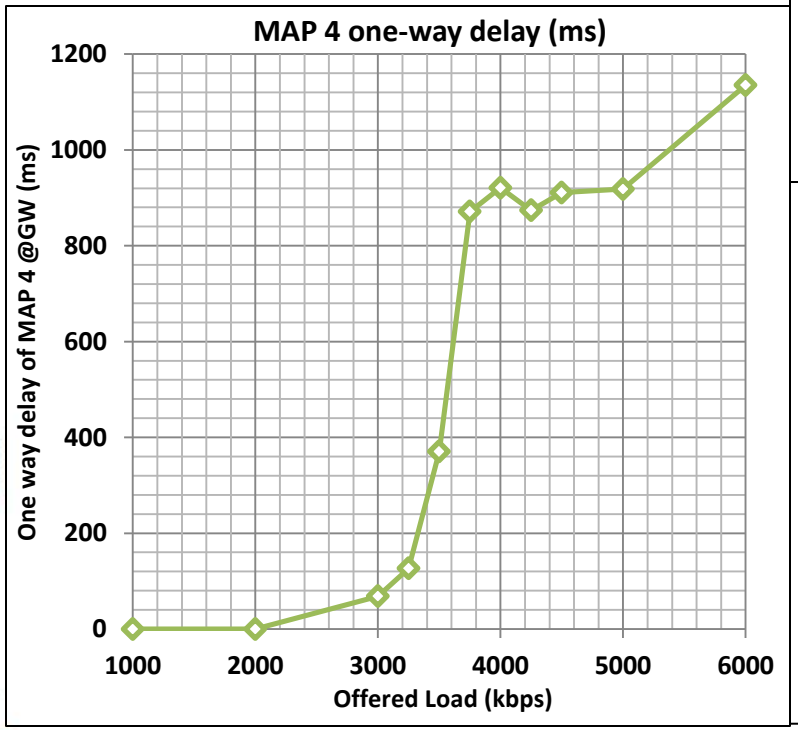


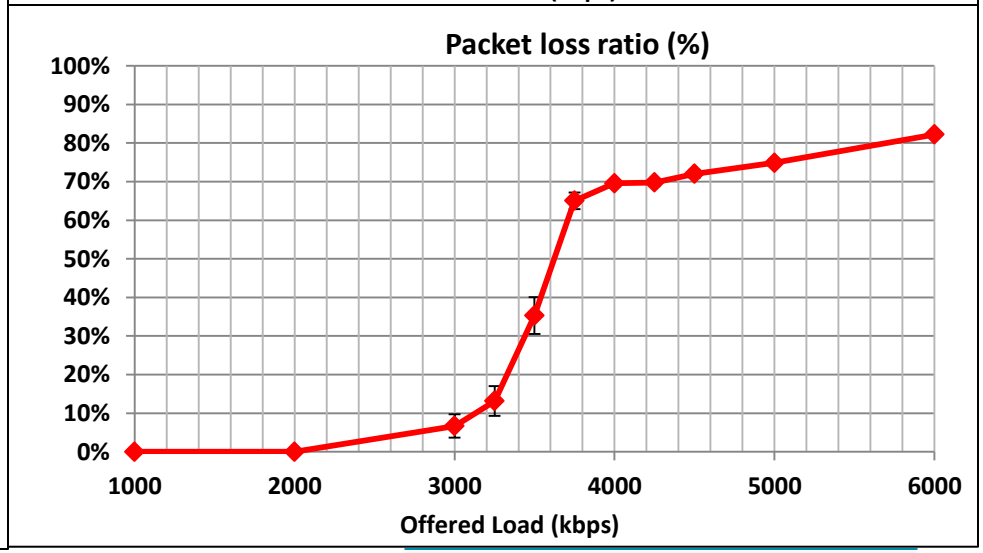
- One Gateway and four MAPs in a chain topology
- Size of data frames: 2000 bytes
- RTS/CTS disabled
- Results are expressed as Goodput and Delay

Results – Case 1 | CSMA/CA only | Single flow through a chain of nodes

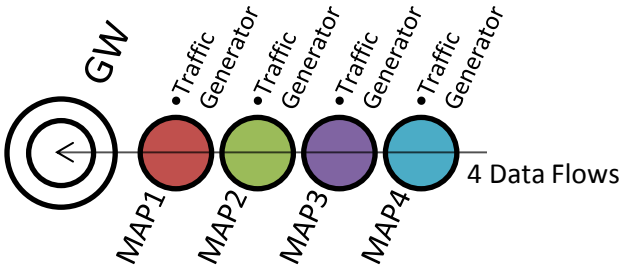


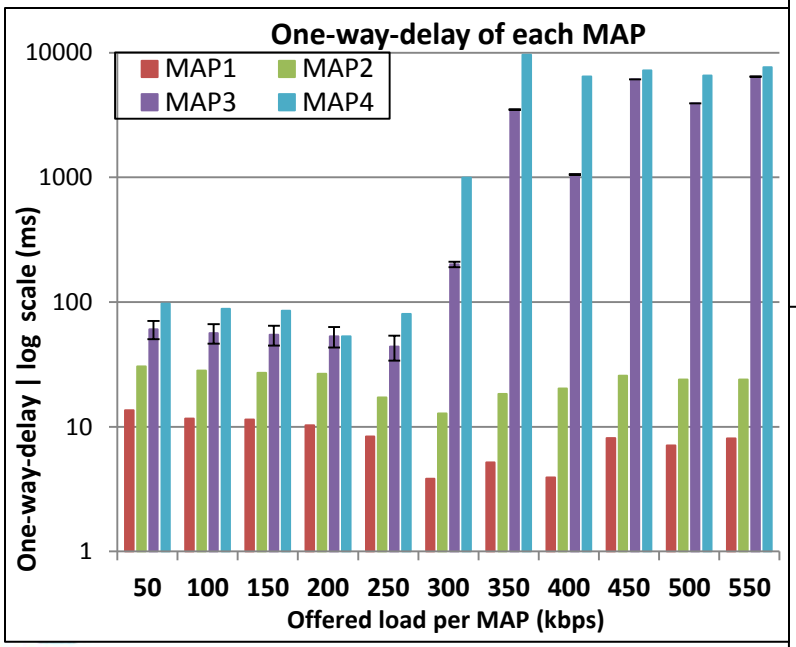


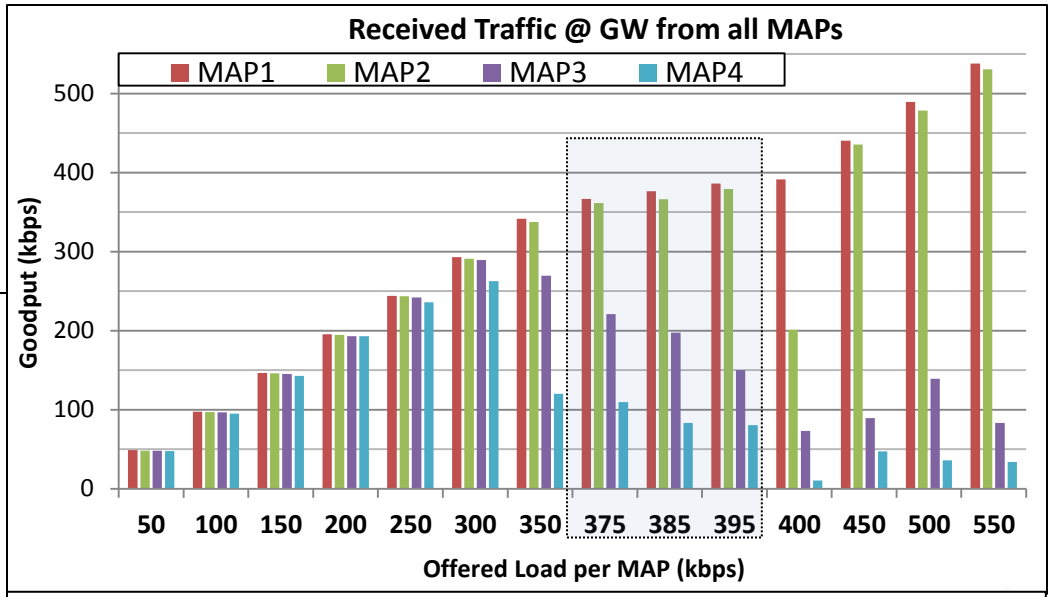


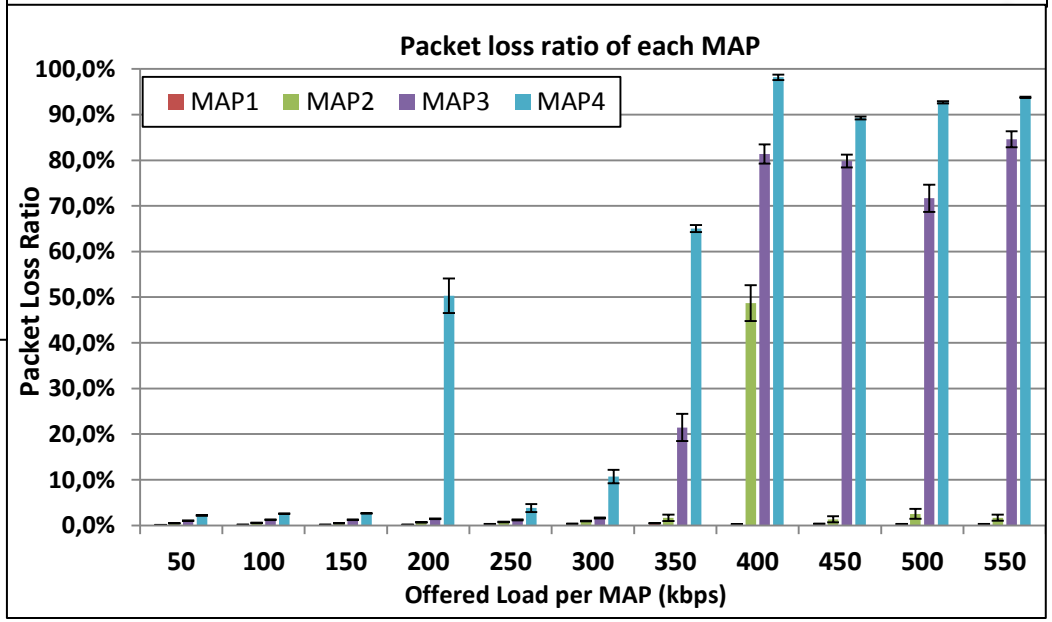


Results – Case 2 | CSMA/CA only | Multiple flows through a chain of nodes



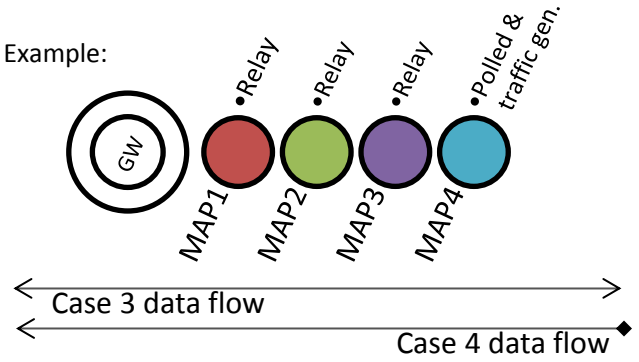


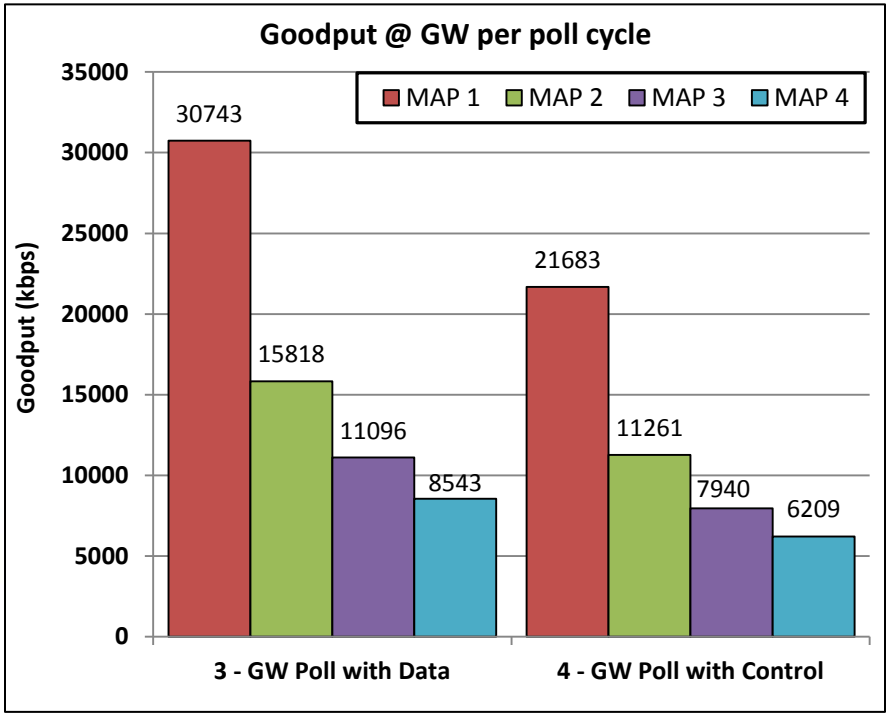


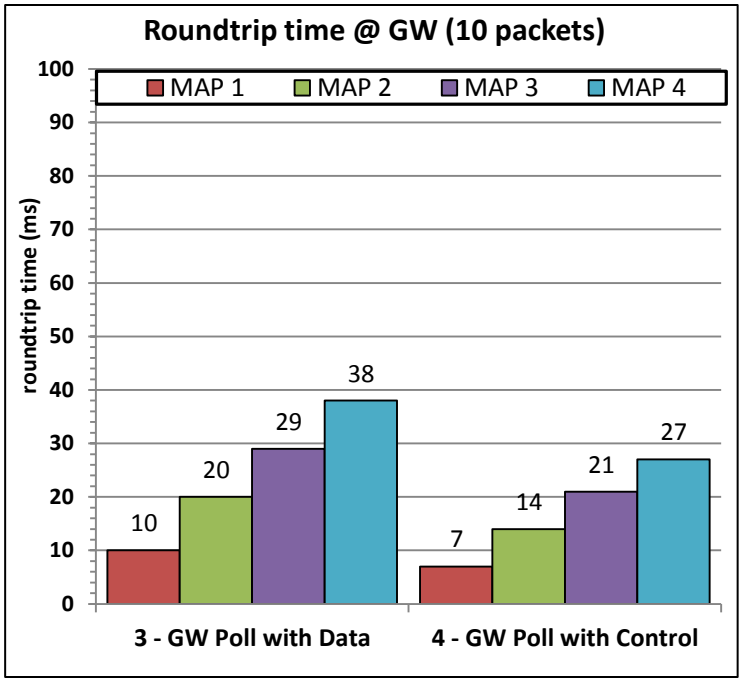


Results – Cases 3 and 4 |PACE| Direct MAP polling

- Gateway polls directly a specific MAP repeatedly
- Polled MAPs are active: Traffic generator
- In Case 3 the poll signal is implicit (Data)
- In Case 4 the poll signal is explicit (Control)



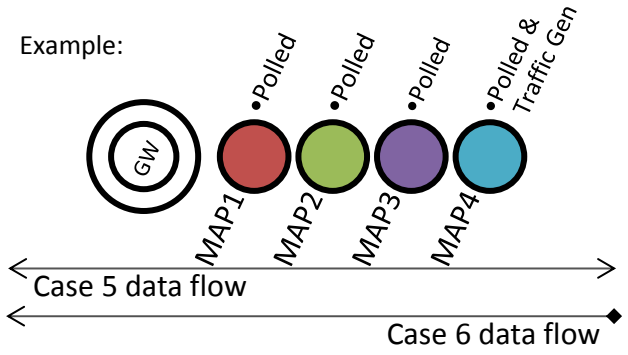


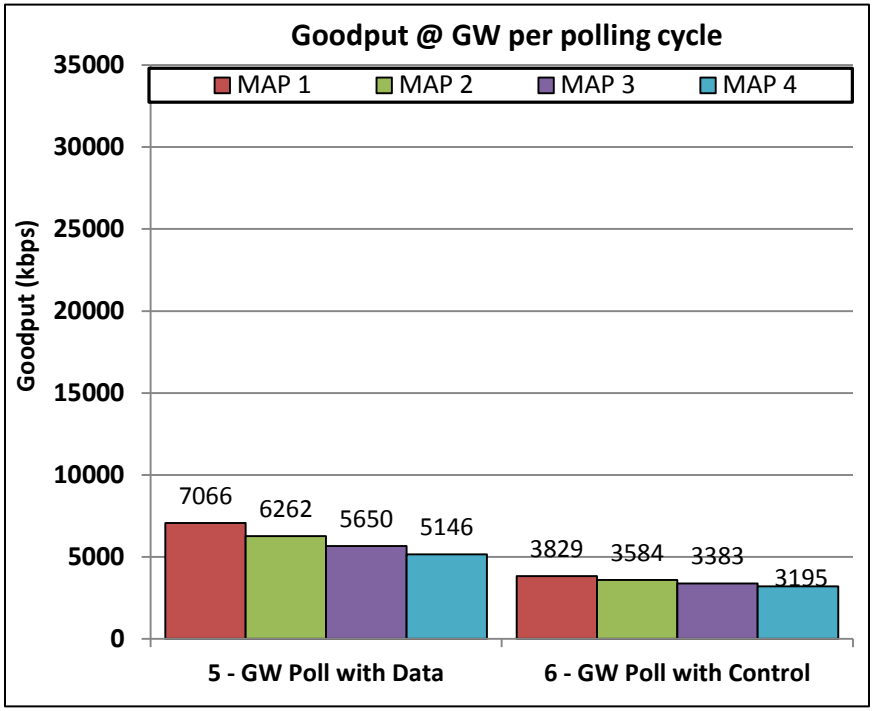


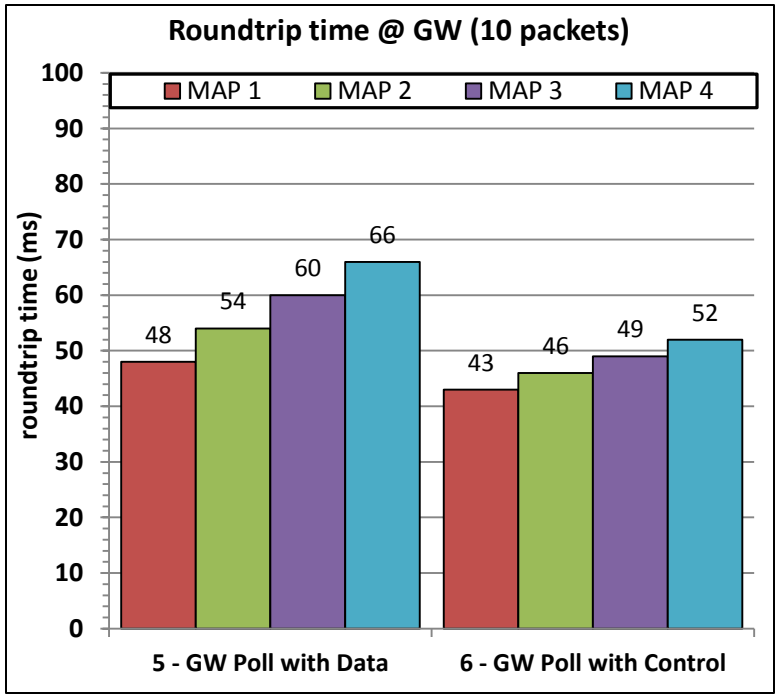
✓ No data packet losses

Results – Cases 5 and 6 | PACE | Full Polling | Only one active MAP

- Gateway polls all MAPs repeatedly
- Only one of the MAPs is active: Traffic generator
- In Case 5 the poll signal is implicit (Data)
- In Case 6 the poll signal is explicit (Control)



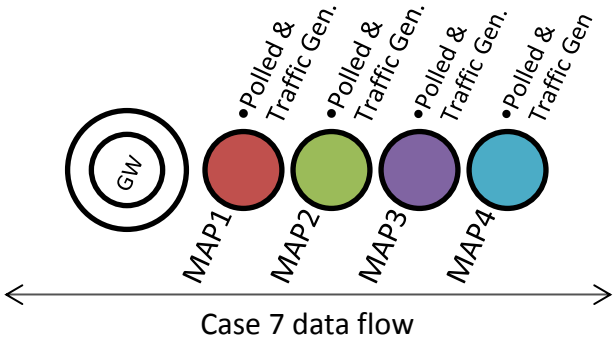


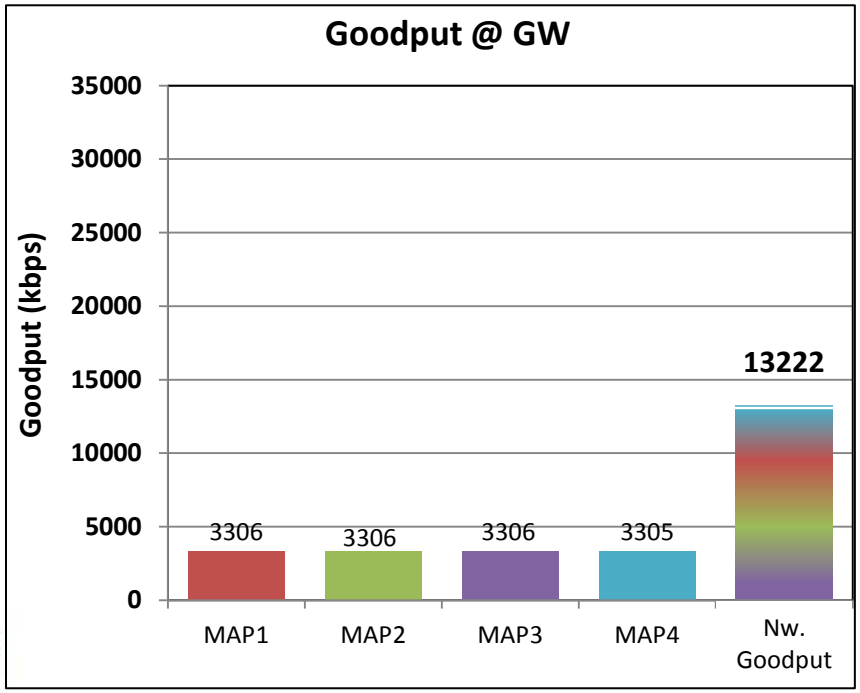


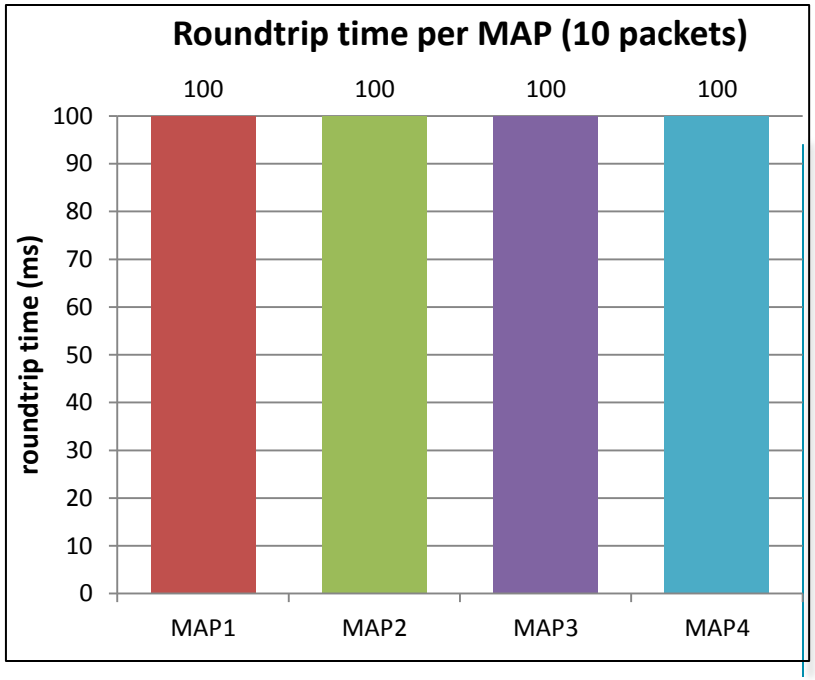
✓ No data packet losses

Results – Case 7| PACE | Full Polling | All MAPs are active

- Gateway polls all MAPs repeatedly with Data
- All nodes are active : Traffic generators







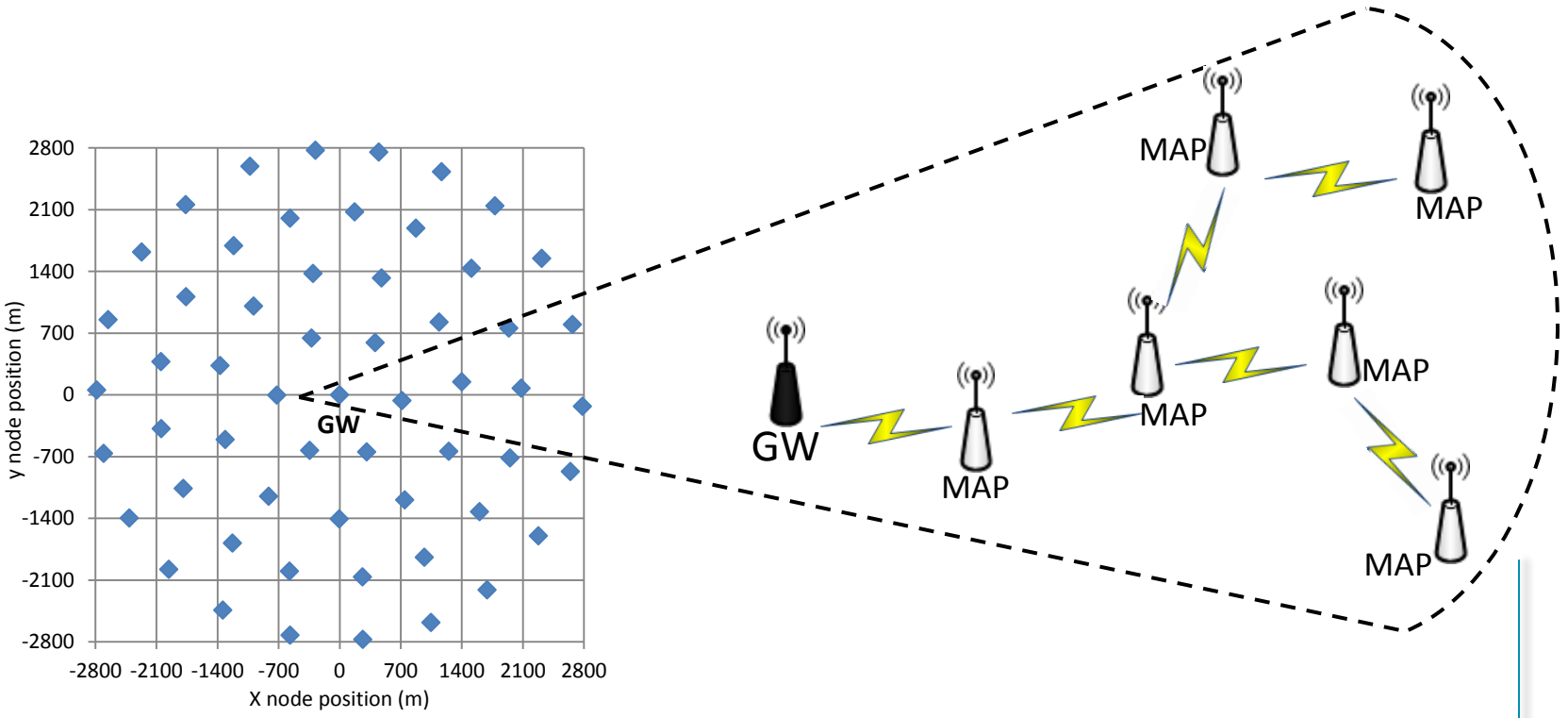
- ✓ No data packet losses
- ✓ Fairness at the data plane level

Results – Brief comparison

- Only MAP4 is active
  - CSMA/CA: 2,7 Mbps with 68 ms delay
  - PACE: at most 8.5 Mbps with 3.8 ms delay
- All MAPs are active
  - CSMA/CA at most in MAP4: 0.260 Mbps with 993ms delay
    - **Total network goodput: 1.1 Mbps**
  - PACE at MAP4: 3.3 Mbps with 10.0 ms delay
    - **Total network goodput : 13.2 Mbps**

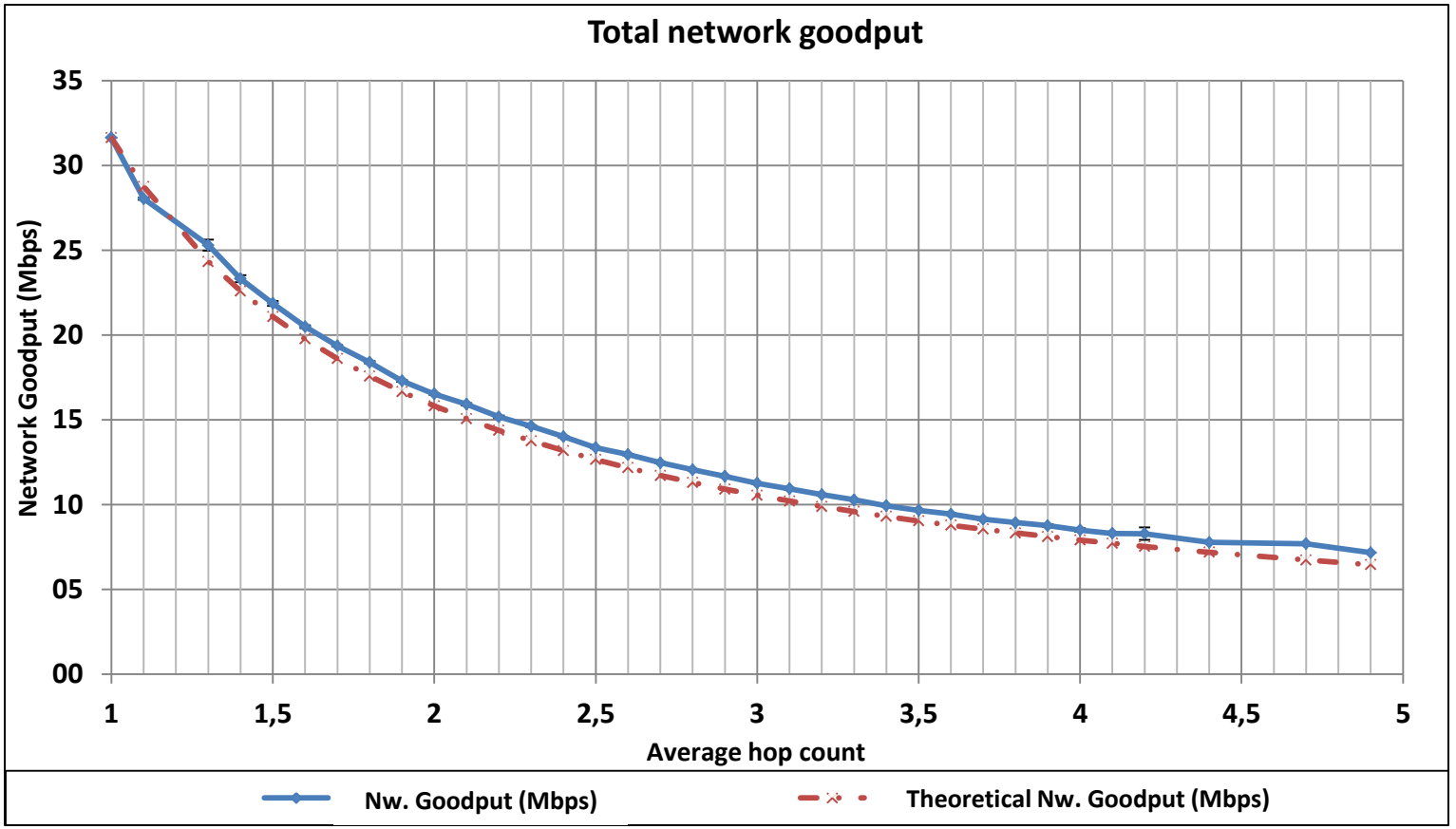
On average PACE is about 750% better!

Scenario 2 – Random Topology



- All MAPs are randomly placed on a radial arrangement
- Random logical topology
- Size of data frames: 2000 bytes
- RTS/CTS disabled
- Results are expressed as Goodput and Delay

Results – Case 8 | PACE | Full Polling | Random topology

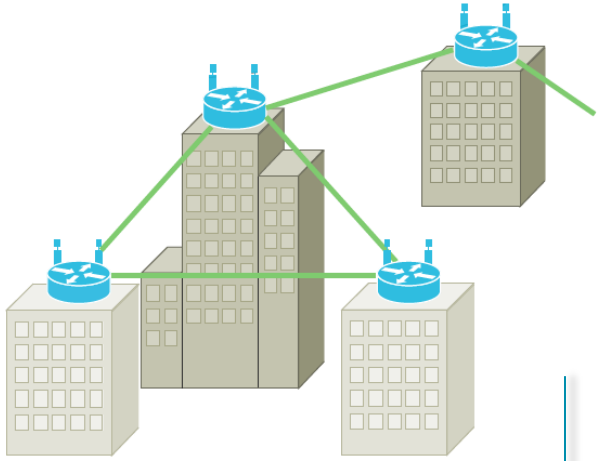


✓ Almost perfect match between theoretical and simulated values

$$C = C_{\text{Wi-Fi link}} / \text{AvgHopCount}$$

Conclusions and future work

- Routing, hidden nodes, congestion control and fairness are major challenges in Stub WMNs
- PACE is a simple and efficient approach
  - Fairness and predictable Stub WMN capacity
  - Easy and fast deployment
- Ongoing and future work
  - Temporal and spatial reuse
  - Integration with Smart Grid systems
  - Implementation in real 802.11-based testbeds
  - QoS: Load balancing, different priorities assigned to flows



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