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Asynchronous Multi Packet Communications in 802.11- based Heterogeneous Networks

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Outline

- Goals
- Physical system
- MAC protocol highlight
- Implementation
- Results
- Conclusions

Topic

802.11 wireless networks with omni-directional antenna equipped nodes:

- allow just a single communication
- not allow multiple communications at the same time

Problem 1

Code Division Multiple Access (CDMA) and **advanced antenna systems** can be adopted to enable multiple **one node to one node communications** or multiple simultaneous reception by one node.

Literature proposals often do not preserve **backward compatibility** with 802.11 legacy stations.

Problem 2

Goals

Non-legacy stations equipped with smart antenna system (SAS):

- support Multi Packet Communication (MPC), maintain backward compatibility, exploit SAS capabilities

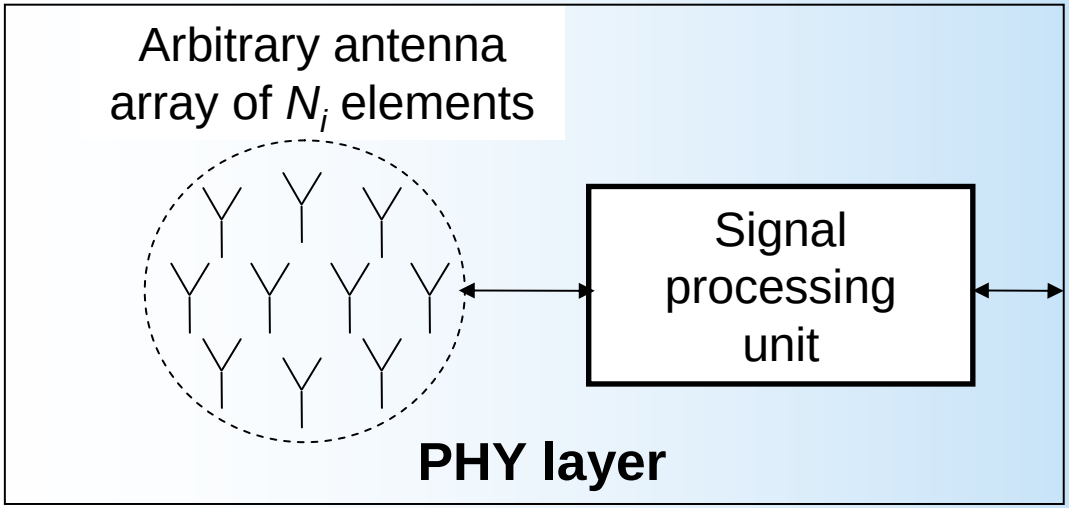
Legacy stations equipped with omni-directional radio:

- communicate with legacy and non-legacy stations, maintenance of 802.11 fairness

Introduce **Asynchronous Multi Packet Communication** in a 802.11 heterogeneous network for simultaneous communications between different node pairs

MAC protocol that exploits SAS to introduce MPC and maintain backward compatibility between legacy and non-legacy stations

Physical System



DOA estimation

Beamforming

Mitigation of interfering sources

Smart antenna system:

- consists of physical antenna array and signal processing unit
- performs direction of arrivals (DOA) estimation
- implements beamforming techniques for antenna directivity
- increases signal-to-interference ratio (SIR) of the received packet
- N_i elements can mitigate N_i-1 interfering sources

MAC protocol (I)

Non-legacy stations:

- are equipped with N_i elements array SAS
- communicates with:
  - legacy stations on Common Channel (CC)
  - non-legacy stations on Space-Division Channel (SDC)
- performs a **learning period** to discover neighbours and their SAS capabilities:
  - Request-To-Send/Clear-To-Send (RTS/CTS) access (4-way handshake) with MoreData flag **enabled** on CC to identify other non-legacy stations
  - Request-To-Send$_{SDC}$/Clear-To-Send$_{SDC}$ (RTS$_{SDC}$/CTS$_{SDC}$) access (4-way handshake) on SDC to identify non-legacy stations SAS capabilities
- after the learning period communicate on SDC

MAC protocol (II)

Non-legacy stations features:

- preamble is added to RTS_{SDC}/CTS_{SDC}/DATA/ACK packets to communicate with non-legacy neighbours (exploited by SAS to perform Direction-Of-Arrivals (DOAs) estimation).
- collect information about legacy neighbours and non-legacy neighbours in a Neighbouring Characteristic Table (NCT)

Legacy behaviour on the CC :

- perform RTS/CTS access (4-way handshake) always on CC
- receive RTS/CTS exchange between non-legacy stations and set the Network Allocation Vector (NAV) and turn-off radio

MAC protocol (III)

Sensing and backoff management

The channel is sensed busy:

Case 1:

-> when the number of ongoing communications **larger** than N_i-1

NB. The N_i elements SAS properly recognizes N_i-1 ongoing communications, otherwise not reliable DOA estimation

Case 2:

-> when RTS_{SDC}/CTS_{SDC} destination or source is the intended destination of the non-legacy station

Case 3:

-> when the number of ongoing communications **larger** than the $\min_{k \epsilon R}(N_k$-1), where R is a sub-set of nodes involved in the ongoing communications

NB. The node i knows all $(N_k\text{-}1)_{k \epsilon R}$ (named load threshold of k-th node Lt_k)

MAC protocol (IV)

Main differences accessing the channel

- different concept “idle channel” for non-legacy nodes
- the non-legacy nodes attempt to access the SDC when a new communication will not destroy (interfere with) ongoing communications
- the maximum number of the sustainable communications is defined by the node with the lower threshold (capability) currently involved in the data exchange.

Avoid starvation for legacy and non-legacy stations independently of their number of antennas

MAC protocol (V)

Channel coding:

Reception of duration T is divided into intervals t_j in which the SIR_j is constant.

The SIR_j in the interval t_j provides the $(\text{Equivalent Rate})_j$ of the interval.

The sum of the $(\text{Equivalent Rate})_j$ ($R_{eq,j}$) weighted on the intervals t_j corresponds to the **Channel Sustainable Rate (CSR)**:

$$CSR = \sum_j R_{eq,j} * \frac{t_j}{T}$$

The packet reception is:

- correct if CSR is **equal or larger** than the channel encoder rate R_t
- unsuccessful otherwise

Implementation (I)

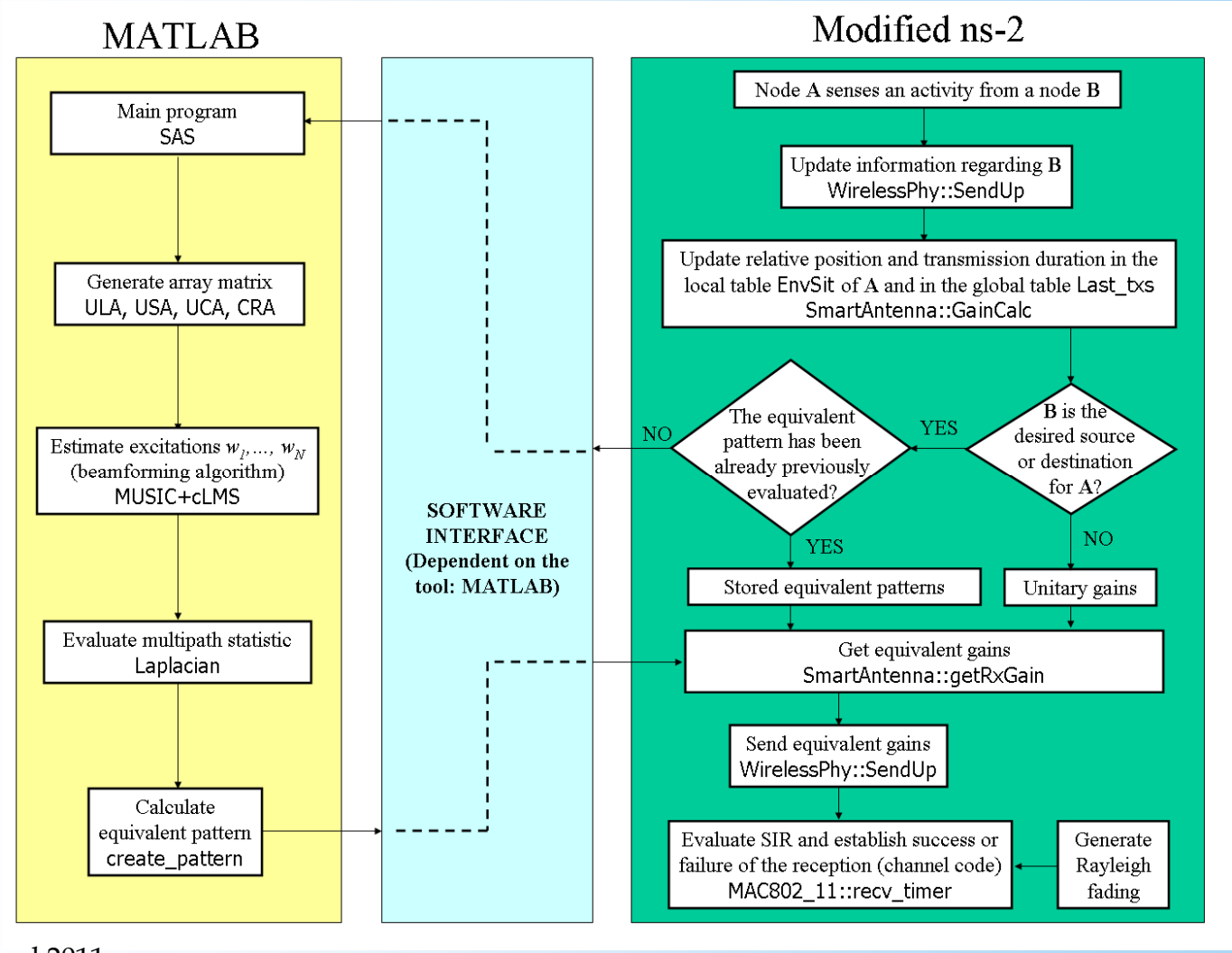
SAS ns-2 class:

- relies on libraries obtained by Matlab Compiler for:
  - ✓ algebra advanced computing
  - ✓ radiation pattern calculation (beamforming)
  - ✓ DOA estimation

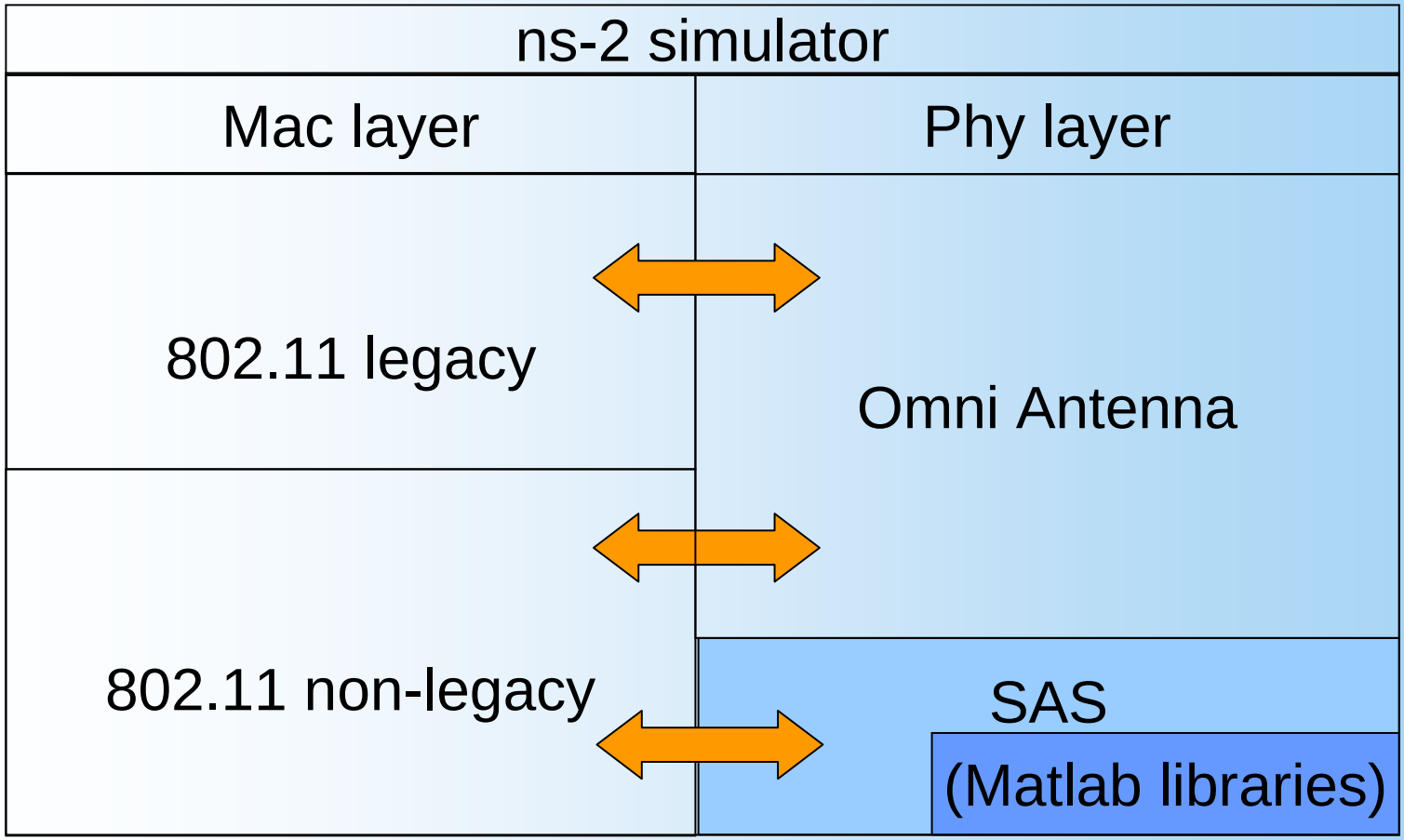
Novel non-legacy MAC ns-2 class:

- calculates received packet SIR
- introduces channel coding techniques in the reception

Implementation (II)



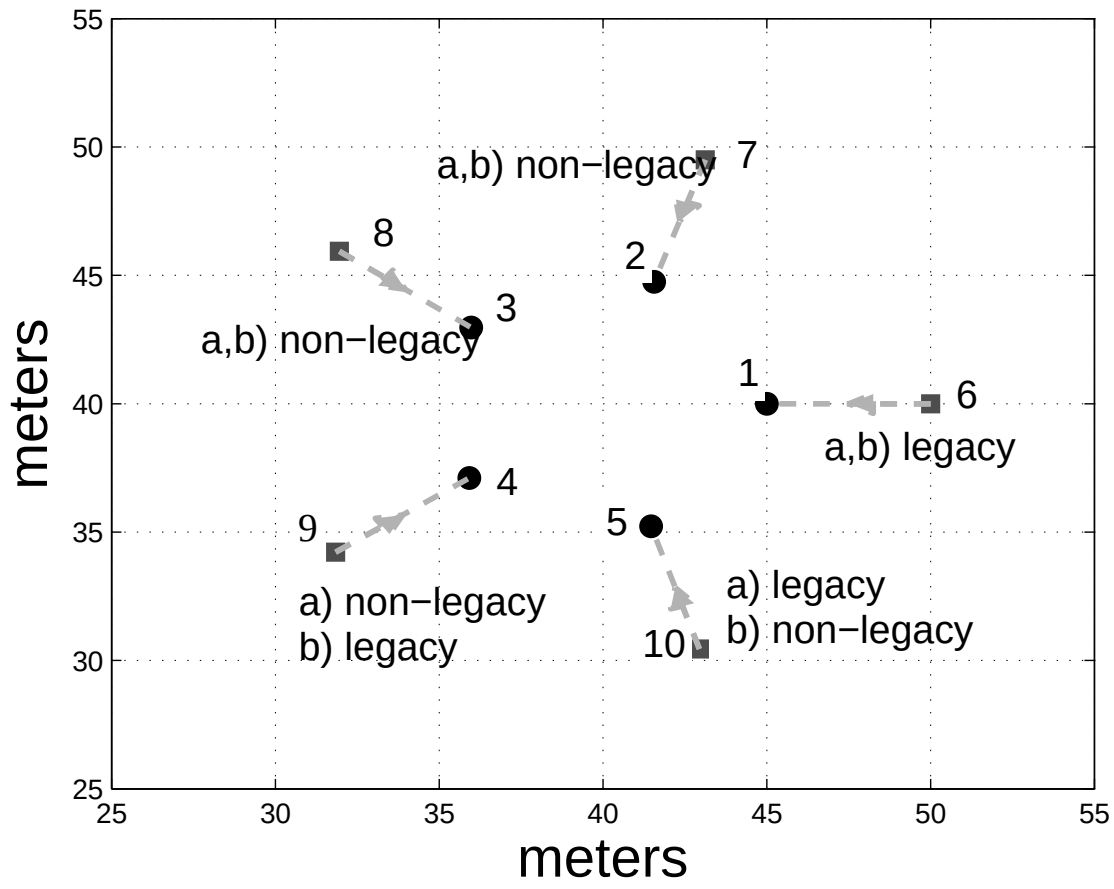
Implementation (III)



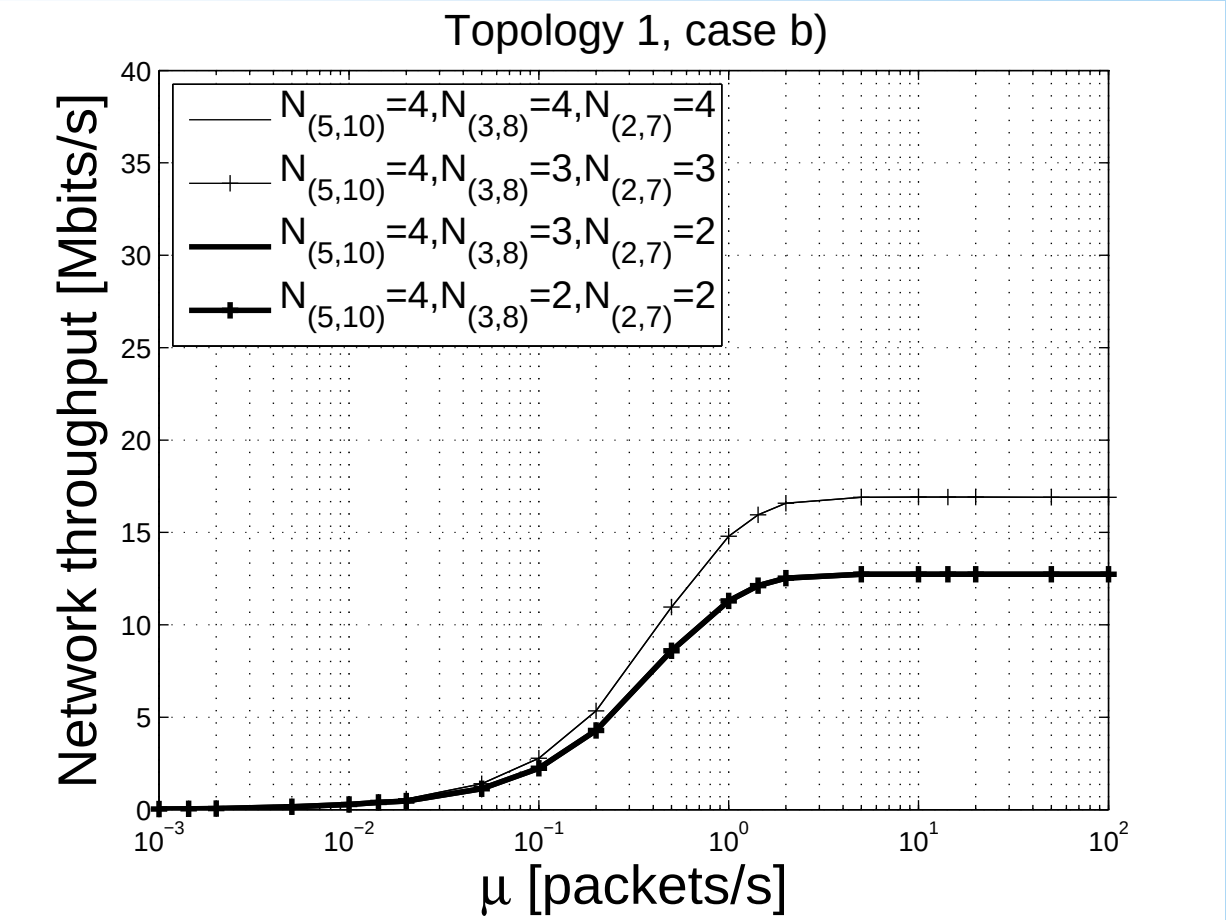
Scenario (I)

Topology **One**:

- 10 nodes on two concentric rings
- case (a) legacy links are adjacent
- case (b) legacy links are separated



Results (I)

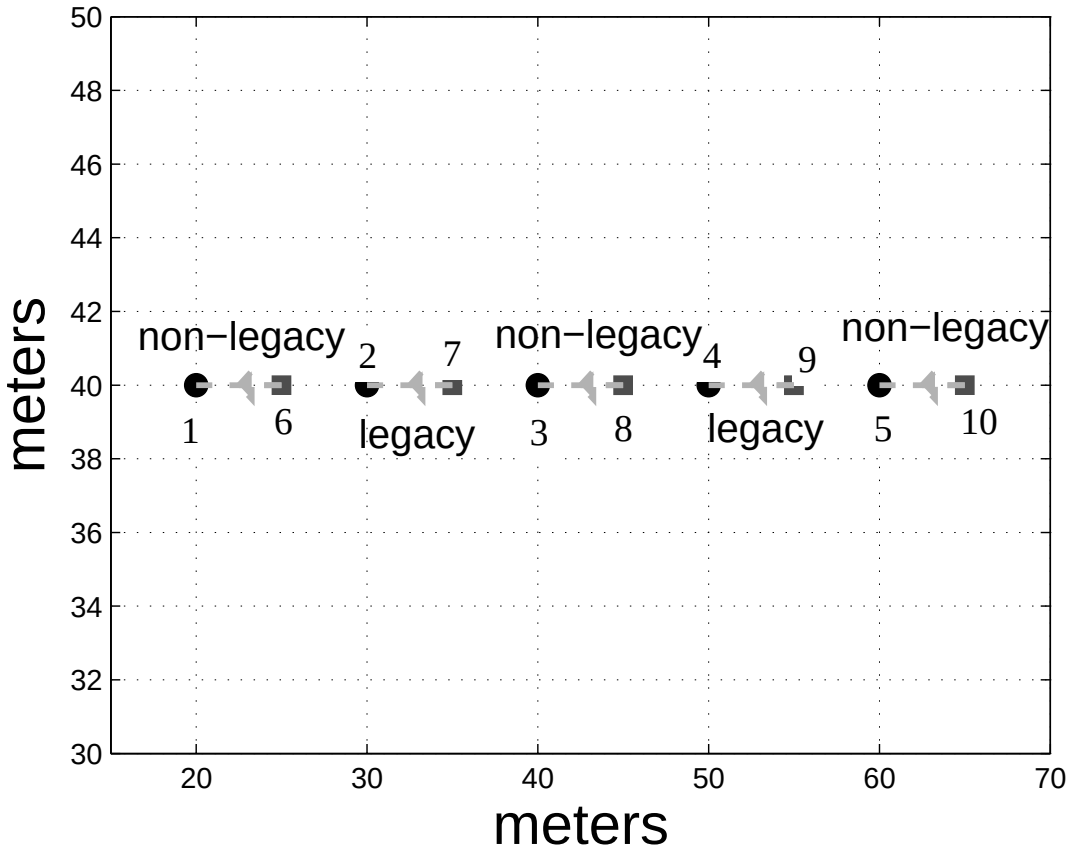


Identical results for the case a)

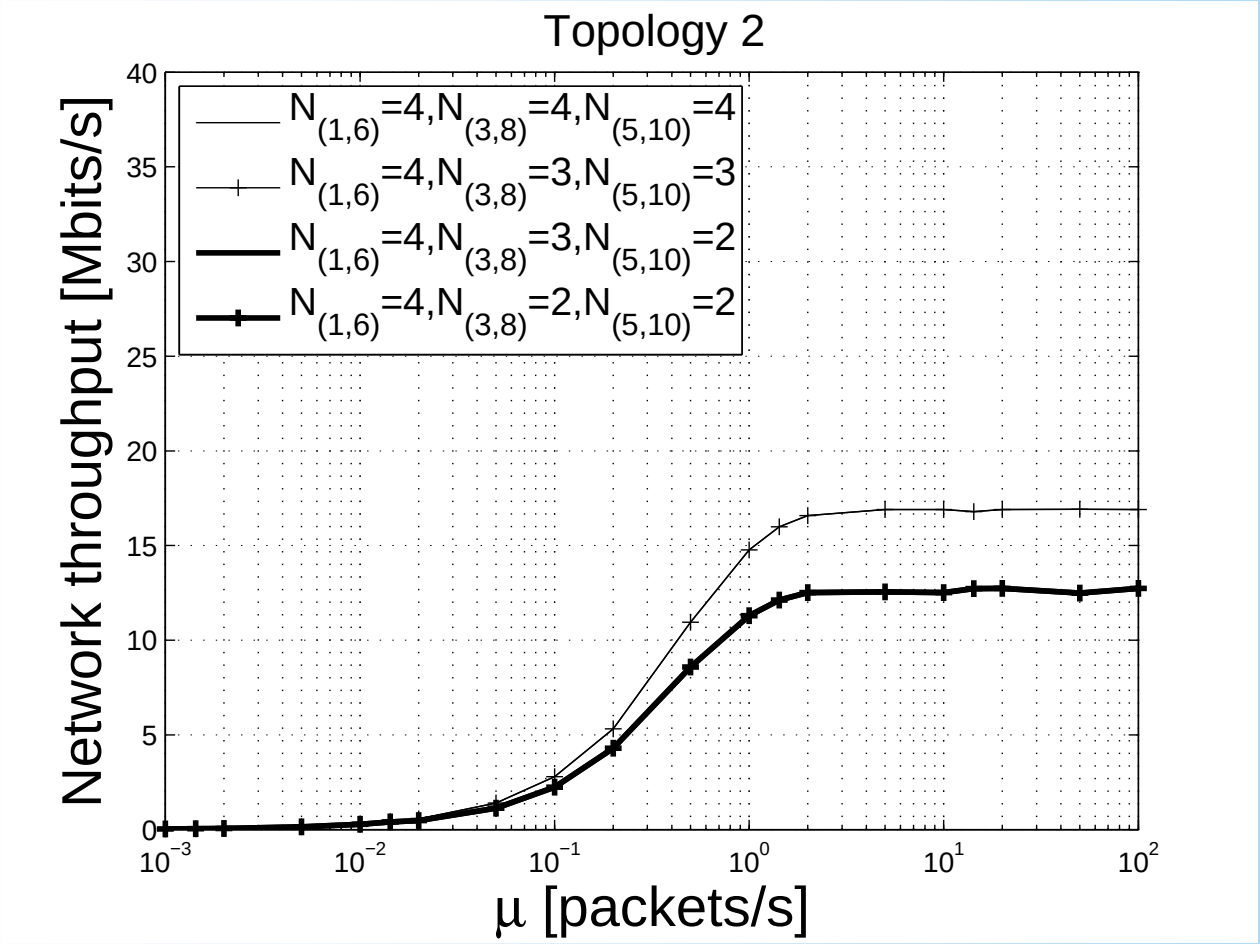
Scenario (II)

Topology **Two**:

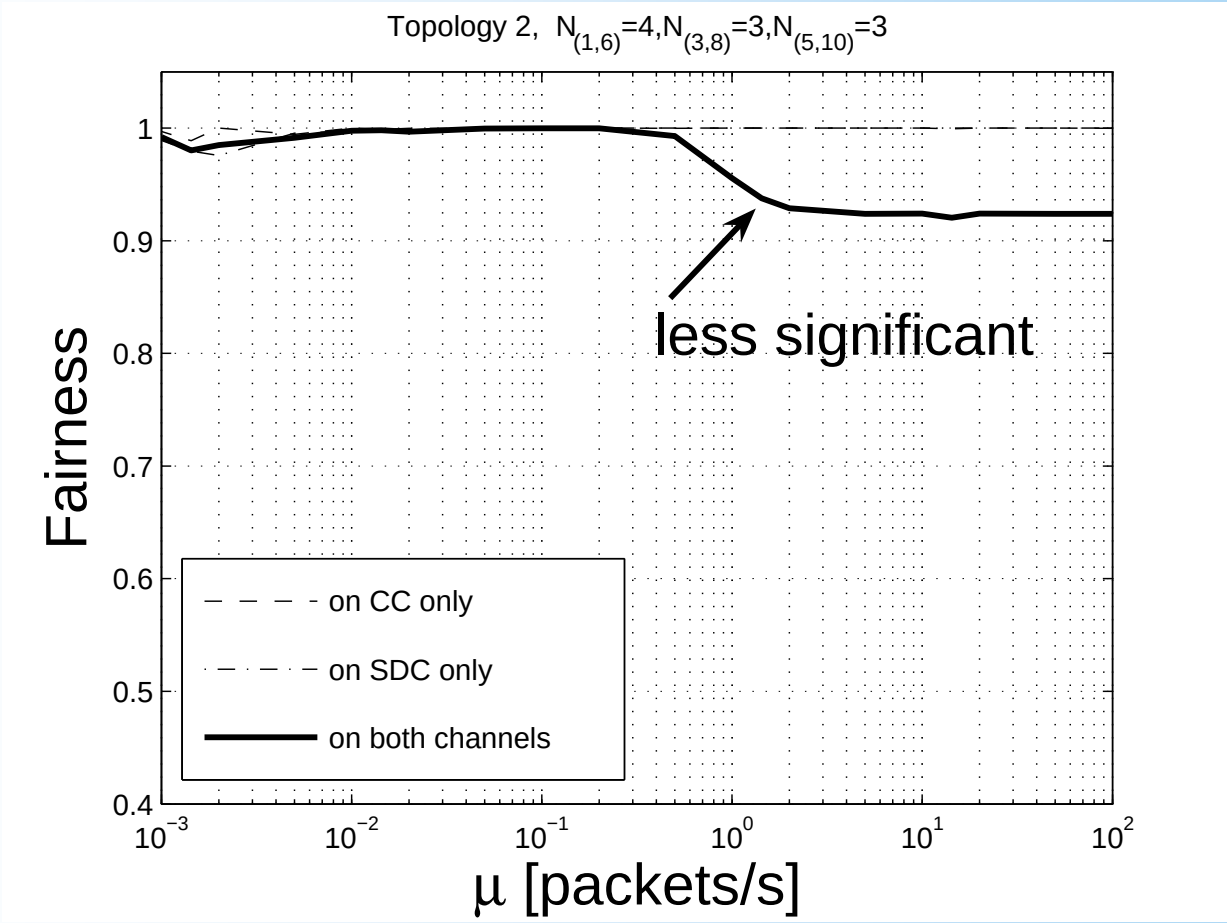
- 10 nodes in-line
- legacy
  links are alternated with non-legacy ones



Results (II)


Topology 2
Network throughput [Mbits/s]
μ [packets/s]
N(1,6)=4,N(3,8)=4,N(5,10)=4
N(1,6)=4,N(3,8)=3,N(5,10)=3
N(1,6)=4,N(3,8)=3,N(5,10)=2
N(1,6)=4,N(3,8)=2,N(5,10)=2
0
5
10
15
20
25
30
35
40
10^-3
10^-2
10^-1
10^0
10^1
10^2

Results (III)


Topology 2, $N_{(1,6)}$=4,$N_{(3,8)}$=3,$N_{(5,10)}$=3
Fairness
1
0.9
0.8
0.7
0.6
0.5
0.4
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
μ [packets/s]
less significant
on CC only
on SDC only
on both channels

Conclusions

Legacy stations:

- contend first channel as in any 802.11 standard network to communicate with legacy and non-legacy stations

Non-legacy stations:

- contend first channel only during learning period, after which communicate on the second channel
- exploit SAS capabilities on second channel
- can communicate with a legacy station on first channel with SAS in “omni-directional mode”
- maintain backward compatibility