A Novel Access Scheme with Localization Capabilities for Multi-Packet Communications in WiFi Networks

F. Babich, M. Comisso and A. Dorni
babich(mcomisso)@units.it, aljosa.dorni@phd.units.it

Department of Industrial and Information Engineering
University of Trieste, Italy
Outline

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

802.11 wireless networks with omni-directional antenna equipped nodes allow just a **single communication** at the same time.

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

**Problem 1**

**Problem 2**

**MAC protocol that exploits Smart Antenna Systems (SASs) to introduce asynchronous Multi-Packet Communication (MPC) in a 802.11 heterogeneous network and maintain backward compatibility between legacy and non-legacy stations.**
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 $N_i - 2$ interfering sources
MAC protocol (I)

Non-legacy stations features:
- perform a learning period on CC to discover neighbors and if they have SAS capabilities
- after the learning period communicate on MCC
- preamble is added on MCC for Direction-Of-Arrivals (DOAs) estimation
- on MCC further information added to packets for exploit channel coding techniques
- collect information about 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 (II)

Channel coding accounting for the method of Sustainable Rate

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 (Equivalent Rate)$_j$ of the interval.

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

$$CSR = \sum_j R_{eq,j} \times \frac{t_j}{T}$$
The method SR is adopted during the channel sensing:

- the SIR is estimated by using:
  - Network Allocation Vector (NAV) used to determine the transmitter
  - Average Gain $G^a$ towards node transmitter
  - Null Gain $G^n$ towards interferers

- the channel is sensed:
  - busy if estimated CSR is equal or larger than the channel encoder rate $R_t$ which can be used at the transmitter
  - unsuccessful otherwise

- the non-legacy nodes attempt to access the MCC when a new communication will not destroy (interfere with) ongoing communications
MAC protocol (IV)

The method SR is adopted during the packet reception:

- the SIR is evaluated by considering:
  - currently active transmitters
  - gains provided by the SAS (DOA estimation + beamforming)
    - main lob towards transmitter
    - nulls toward interfering sources

- the packet is considered:
  - properly received if CSR is equal or larger than the channel encoder rate $R_t$ of the transmitter
  - unsuccessful otherwise
Implementation (I)

Implemented in a hybrid discrete-time discrete-event Matlab-ns2 simulator by adding new ns2 classes

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
Scenario (I)

Topography:
- 10 links: 6 links non-legacy-non-legacy and 4 links legacy-legacy
- random positioning
Results (I)

### Results (II)

Single-node saturation throughput (in Mbits/s) and Jain’s fairness index for the pairs operating in the MCC

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>9-10</td>
<td>3.55 2.61</td>
<td>3.55 1.47</td>
<td>3.30 2.60</td>
<td>3.34 1.52</td>
<td></td>
</tr>
<tr>
<td>11-12</td>
<td>1.03 1.25</td>
<td>1.04 0.71</td>
<td>0.75 1.01</td>
<td>1.50 0.57</td>
<td></td>
</tr>
<tr>
<td>13-14</td>
<td>3.27 2.64</td>
<td>3.27 1.45</td>
<td>1.95 2.05</td>
<td>1.84 1.26</td>
<td></td>
</tr>
<tr>
<td>15-16</td>
<td>3.27 2.60</td>
<td>3.27 2.82</td>
<td>2.91 2.65</td>
<td>2.22 2.67</td>
<td></td>
</tr>
<tr>
<td>17-18</td>
<td>2.39 2.30</td>
<td>2.39 1.17</td>
<td>1.63 1.44</td>
<td>0.78 0.83</td>
<td></td>
</tr>
<tr>
<td>19-20</td>
<td>3.27 2.62</td>
<td>3.27 1.46</td>
<td>2.12 1.95</td>
<td>0.54 1.35</td>
<td></td>
</tr>
<tr>
<td>Fairness</td>
<td>0.91 0.96</td>
<td>0.91 0.85</td>
<td>0.87 0.92</td>
<td>0.77 1.35</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

The proposed MAC protocol provides the following advantages:

- can operate in asynchronous heterogeneous networks
- exploits SAS capabilities to allow MPC
- maintains backward compatibility
- leads to a throughput increase also with respect to the 802.11 super-g technology

Further performance improvements can be obtained by adopting channel coding techniques more efficient than the standard convolutional codes:

- results have shown that turbo codes may be an interesting solution
The proposed MAC protocol:

- exploit SAS, which implements DOA estimation
- requires to know the position of the neighbours
- exchange SAS capabilities through additional field in the packet header

SAS estimates the DOA, hence distance is also required. (2 angle, 2 distance -> accurate positioning by triangulation)
- more/less accuracy in outdoor/indoor scenario

To investigate the accuracy and precision for localization system based on SAS
Localization highlight (II)

SAS:
- expensive
- non suitable for on-the-shelf product

Switched beam antenna may be an interesting solution.

To investigate the best tradeoff between accuracy and precision exploiting switched beam antenna instead of SAS.
Localization highlight (III)

Implementation issues:

- **Software Defined Radio:**
  - Gnuradio + UHD
  - USRP1 & USRP N210

- **Smart Antenna System:**
  - Off-line processing
  - Real-time system

- **Switched-beam Antenna System:**
  - Comparison with SAS
  - Off-line processing