Fast Link Adaptation for IEEE 802.11n

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IEEE 802.11n WLAN Overview and Background

- IEEE 802.11n (will be ratified next year) is based on multiple input multiple output (MIMO) & orthogonal frequency division multiplexing (OFDM).
- Objectives of IEEE 802.11n are to:
  - Support applications requiring high data rates like multiple High Definition TV streaming.
  - Provide high throughput.
  - Enhance the range.
  - Keep backward compatibility with IEEE 802.11a/b/g (legacy devices).
  - IEEE 802.11n is based on non-orthogonal codes.
- New medium access control (MAC) features, e.g., frame aggregation to increase throughput.
- PHY specification summary:
  - Peak data rates: 6 to 600 Mbps in 2.4 & 5 GHz bands.
  - Channel BW:
    - 20 MHz: (mandatory); 54 Data SCs & 4 Pilot SCs.
    - 40 MHz: 108 Data SCs & 6 Pilot SCs.
  - Modulation: BPSK, QPSK, 16QAM & 64QAM.
  - Spatial streams: up to 4.
  - Convolutional code: generator (133, 171)8; Constraint length 7; basic code rate 1/2.
  - Optional: link adaptation, beamforming, LDPC, antenna selection, etc.

IEEE Channel Models [1]

- IEEE channel models are slow time varying channels.
- Only scatterers are moving with velocity of 1.2 km/h.
- No explicit relative velocity between Tx and Rx.
- IEEE channels are modelled by cluster modelling approach.

[1]: TGn Channel Models for IEEE 802.11 WLAN, 802.11-03/940r4, May 2004
Example - Channel Model B: Power Delay Profile

- PDP can be modelled as an exponential decaying function.
- Each cluster is caused by a specific group of scatterers and denotes modelling of independent propagation paths.
- Multipath in a cluster arrive at the Rx from the same general direction.

Channel Model B: Time-Variant Response

- We can see two clusters:
  - First cluster starts from 1st Tap (delay 6 [ns])
  - Second cluster starts from 3rd Tap (delay 20 [ns])

Time Variant Transfer Function

Channel Model B Channel Model E

Coherence Bandwidth

- Coherence bandwidth for channel B (4.9 MHz) > channel E (0.9 MHz).

Channel Quality Over Time

Channel Model B Channel Model E

Channel Model B: Correlation Time Function

- Coherence time is decreasing with the increase of speed of scatterers.

<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>Coherence Time [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>13.8</td>
</tr>
<tr>
<td>2.0</td>
<td>8.0</td>
</tr>
<tr>
<td>3.0</td>
<td>5.3</td>
</tr>
<tr>
<td>4.0</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Definition of LA in the IEEE 802.11n

- Support of FLA
  - An immediate response
  - An unsolicited (delayed) response — delay is unconstrained.

- A transmitter can request MCS by setting MCS Request field to 1 in LA control field by:
  - Sounding packet. It sounds all the supported spatial dimensions.
  - A receiver can send estimated MCS by setting the chosen value from 0 - 76 in MCS feedback field and pair the sequence number of MCS request and MCS Feedback Seq Number.

General Concept of FLA

- In this project work, CSI:
  - Post-processing links
  - Soft bits input to Viterbi decoder

- FLA comprises:
  - PER estimation block which contains LDGM
  - Search mechanism: Finds a suitable MCS fulfilling PER target

- Concept of LQM mathematically.

\[
\text{PER}_{\text{estimation}}(\text{CS}) = \frac{\text{PER}_{\text{estimation}}(\text{LQM})}{\text{M}(\text{SNR}), \ldots}
\]
Example of the LQMs based on mutual information: MMIBM and MMIRM.

Simulations in the AWGN channel gives the relation of the mapping from LQM to PERref.

The regressions are used for the mapping function $f_{MCSPL}(LQM)$.

Packet Length (PL) = 1024 Bytes

Example of pdf (from histogram) of estimation errors for channel model B.

258 measurements (MCS 0-15).

Optimization and evaluation are done on the same set of measurements.

EESM, MIESM and MMIBM are the most accurate LQMs; MMIRM is less accurate and RawBER is the least accurate.

We consider the following problem

$$\max_{MCS} \quad TP(MCS)$$

s.t. $\text{PER}(MCS) \leq \text{PER}_{\text{Threshold}}$

Discrete problem with

$\Omega(N_T) = \{\text{allowed MCS} \mid \Omega(1) = 8, \Omega(2) = 16, \Omega(2 + \text{unequal})\} = 22$

- The problem is structured, so it is possible to solve it easier than the exhaustive method.
- If some subcarriers are in deep fade, it is more important to have a large Hamming distance than a large Euclidean distance [1].

$\text{PER}(MCS_x) \leq \text{PER}(MCS_y)$

$\Rightarrow TP(MCS_x) \leq TP(MCS_y)$

Proposed both optimal search methods and suboptimal with a smaller computational burden.

Propose a less tight but useful bound with complexity

$$O = N_{MCS} \times N_{SNR} \times N_{CR} \times N_{PT}$$

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IEEE Channel Models

Link Adaptation for IEEE 802.11n

Accuracy, Search and Bounds

Results

Conclusions
### Upper Bound of any LA Algorithm

- **Upper bound of TP (and lower bound on PER)**

  ![Graph showing TP and PER](image)

- **$\text{PER}_{UB} \leq \text{PER}(\text{MCSx})$** This is the lower bound on PER.
- The bound is introduced because all MCS are under trial.
- Let $\text{MCS}$ be the MCS selected with genie knowledge of the PER
- The $\text{MCS}$ succeeds with the same probability for genie as for upper bound.
- For $\text{TP}_{UB}$, MCSs prior to $\text{MCS}$ can succeed.
- If any failure, MCS with lower MCP can succeed.

\[
\text{TP}_{UB} \geq \text{TP}_{Genie} \geq \text{TP}_{LA \text{ algorithm}}
\]

### Agenda

1. IEEE 802.11n WLAN Overview and Background
2. IEEE Channel Models
3. Link Adaptation for IEEE 802.11n
4. Accuracy, Search and Bounds
5. Results
6. Conclusions

### Numerical Results – 1x1, Channel Model B

- Evaluated using the Freudenthaler scheme.
- Consider MIESM and MMIRM. Other methods yield almost same performance.

- Larger gain compared to PER constraint envelope (520% at SNR = 22 dB).
- Largest gain in the mid SNR regime. Bounded by the available MCSs.

### Numerical Results – 1x1, Channel Model E

- Distance to PER constraint envelope is smaller and gap to upper bound is larger compared to the example for channel model B.
- Benefit of FLA is largest in settings with the lowest diversity.
- FLA exploits varying channel quality.

### Numerical Results – 2x2, Channel Model B

- Spatial streams is $\leq$ number of transmit antennas
- LQMs utilizing post-processing SINRs can calculate the required SINRs for the cases of a lower number of spatial streams. Only constraint is that all spatial dimensions are sounded.
- We have not identified a good solution for calculating this under MMIRM (uses the soft bits and not SINR).

### Numerical Results – Feedback Delay and Speed

- At coherence time: ~20% loss in TP and ~25% PER
- PER increases fast to a non acceptable level.
- The delay is unconstrained.
- The speed of the scatterers (antennas) are unconstrained in practical conditions.
- Outer loop adjusting selection threshold such that the desired PER can be met.
Investigated background, IEEE 802.11n implements MIMO-BICM-OFDM.
IEEE WLAN channel models.

Link Adaptation
- FLA has advantages compared to SLA.
- Protocol for LA.

FLA comprises
- PER Estimation using LQM
  - Mapping fading channel into an equivalent AWGN channel.
  - Methods considered: RawBER (effective), SNR effective and mutual information.
  - Evaluated the accuracy. EESM, MMIBM and MIESM are the most accurate. MMIRM is slightly less accurate and RawBER is the least accurate method.
- Search Criteria and Optimality
- Bounds
  - FLA algorithm under investigation and bound for any link adaptation algorithm for the settings applied.
  - Unconstrained delay and speed of scatterers.
  - Requires outer loop to maintain target PER because the FLA algorithm can not adjust it by itself.
  - FLA exploits lack of diversity. Most pronounced gain in the mid SNR regime.
  - In general, EESM, MMIBM and MIESM are the preferred LQMs to RawBER and MMIRM in the FLA algorithm for IEEE 802.11n.

Thank you