Wireless Network Coexistence Through Regular Channel Occupation

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Overview

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Motivation

- Spectrum demand for wireless communication is growing
- All suitable frequency bands are assigned
- Operators deploying a new system in licensed bands have to:
  - Use a license they own
  - Buy a license from a license holder
  - Get a license for rededicated spectrum
- Alternative: license-exempt operation:
  - In bands dedicated for license-exempt operation
    - Ex. ISM: 2.4 GHz - 2.5 GHz, 5.725 GHz – 5.875 GHz
  - In licensed bands when license holder is absent
    - Non-exclusive license: 3.650 GHz – 3.700 GHz in US

⇒ Spectrum for license-exempt operation is available
⇒ Can be used at no/low costs
⇒ Requires no/less network planning
Related Work and Standards

Examples for license-exempt operation:

- **IEEE 802.11 (WLAN): CSMA/CA**
  - Backoff reduces channel utilization
  - Unpredictable delays
  - Channel capacity depends on number of stations

- **IEEE 802.15.1 (Bluetooth):** Frequency hopping
  - Spectrum smoothing
  - Only possible for low power / low distance

- **IEEE 802.16h (License-exempt WiMAX):** TDMA
  - Exploit periodic MAC frame structure (5 ms – 20 ms frame duration)
  - Multiplex multiple systems in time domain
  - Delay depends on MAC frame lengths and system count

<table>
<thead>
<tr>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
<th>System 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC frame n</td>
<td>MAC frame n+1</td>
<td>MAC frame n+1</td>
<td>MAC frame n+1</td>
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</tbody>
</table>

Preamble, Frame Control Header (FCH), Maps
Related Work and Standards

- Digital Enhanced Cordless Telecommunications (DECT)
  - 10 frequency channels
  - TDMA 24 slots, 12 per direction (DL/UL),
  - Possibly unsynchronized in time domain among different systems
  - Choose slot with lowest RSSI for new connection
  - Best performance if channel quality remains good in the future
  => Must be predictable / have low variance

Slot length 416.7 µs

Frame length 10 ms, 24 slots
Proposed Method

Can we multiplex IEEE 802.16 systems in time domain on smaller time scale than MAC frame duration?

IEEE 802.16 frame structure

- Preamble, FCH, and Map at frame start
  - Whole frame could be lost for communication if not received
- Time division duplex (TDD)
- Downlink (DL) and uplink (UL) subframes
  - PDUs scheduled one after another
  - Idle periods at end of DL and UL subframe at low loads
Proposed Method

Idea: multiplex on subframe level

- Two system solution: fill subframes from front and back
- Precondition: systems have to synchronize DL/UL turnaround point
- Varying loads in each frame can cause simultaneous operation
- More than two systems: additional synchronization required
Analytic Results

Analytic results:
- Frame length is $T$
- $N(T)$ is the counting process of PDU arrivals during $T$
- $N(T)$ is Poisson distributed for neg. exponential PDU interarrival time
- $p(s(t))$ is the processing time PDF of a PDU (transmission time)
- $p(S(t)|N(T) = n) = p(s(t))^{(n)}$ is the processing time PDF of $n$ PDUs (service period (SP) duration)

$$p(S(t)) = \sum_{x=0}^{\infty} P(N(T) = x) p(S(t) | x) = \sum_{x=0}^{\infty} P(N(T) = x) p(s)^{(x)}$$
Analytic Results

Example: DL SP duration distribution for two different processing time distributions

- $T = 10 \text{ ms} = 720 \text{ symbols}$, symbol duration $t_{sym} \approx 13.9 \mu\text{s}$
- Neg. exp. interarrival time
- Processing time: neg. exp. / “WiMAX PHY Modes”, $\mu^{-1} = 20.3725 \ t_{sym}$
- Traffic load $\rho = 0.375$
- Zero size Preamble, FCH, Map

\[
\mu^{-1} = 20.3725 \ t_{sym}
\]
Analytic Results

Influence of offered load:
- Assumption: UL subframe starts at $T/2$
- Increasing load increases mean service period duration

\[
\begin{align*}
\mu^{-1} &= 20.3725 \\
\rho &= 0.25 \\
\rho &= 0.375 \\
\rho &= 0.5 \\
\rho &= 0.625
\end{align*}
\]
Analytic Results

Influence of mean PDU transmission time:
- Variance decreases as transmission time decreases (shorter PDU, better PHY mode)

\[ \rho = 0.375 \]
- Neg. exp. IAT
- Neg. exp. PT
Analytic Results

What is the probability of simultaneous operation?

\[ P_{\text{Coll}} = P(S_{DL,1}(t) \geq S_{DL,2}(\tau)) \]

\[ = \int_0^T \int_0^t p(S_{DL,1}(t), S_{DL,2}(\tau)) dtd\tau \]

\[ = \int_0^T \int_0^t p(S_{DL,1}(t)) p(S_{DL,2}(\tau)) dtd\tau \]

What is the expected duration relative to \( T \)?

\[ 2E_{P_{\text{Coll}}} [t - \tau] / T \]

\[ = 2 \int_0^T \int_0^t p(S_{DL,1}(t)) p(S_{DL,2}(\tau))(t - \tau) dtd\tau / T \]
Summary:
• Presented scheme assures predictable channel occupation
• Simultaneous operation is possible but the probability could be low enough for some applications
• Traffic classes are possible when scheduling at offsets with different collision probabilities

Outlook:
• Compare with 802.16h frame multiplexing
• Solutions for more than two systems
• Include node positions and SINR in model
Thank you for your attention!

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