Interference Evaluation in ECMA-368 WPAN with DRP MAC Protocol

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26/03/2014
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Motivation

• Wireless communication in residential home environments covers wide range of applications

• Common market trend from multimedia capable devices (DEVs) towards applications demanding for very high data rate transmission service: TV and video data transmission

• Outdated Wifi’s mono-cluster approach replaced by multi-cluster home networks yielding intended high data throughput in limited area [1]

➡️ Motivation to use UWB ECMA-368 for short range ad-hoc communication in residential home environment

Problem Description

• Widespread use of wireless communication systems operating in license-exempt frequency bands goes along densely populated network scenarios

• DEV applies reservation based DRP controlled medium access to transmit user data reliably carried in successively recurring Medium Access Slots (MASs)

• Spatial reuse of MAS channel resources in not fully meshed network scenarios causes interference to user data frame transmission

➔ Limits achievable cluster data throughput and coverage range
ECMA-368[2]: Medium Access Control (MAC) Overview

- Fully distributed MAC:
  - DEVs unhide DEV located in the neighbourhood through short management frames broadcasted during Beacon Period (BP)
  - DEV negotiates MASs for user data frame transmission in advance to carry user data frames during Data Transfer Period (DTP)

- Management frames carried in Beacon Slots (BSs) are protected from interference caused by transmission in the two hop neighbourhood
- User data frames carried in MAS exclusively are protected from interference caused by DEVs data transmissions located in one hop Beacon Group (BG)

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ECMA-368: Medium Access Control
Beacon Period (BP)

- Beacons are broadcasted in recurring BSs

- Several Information Elements (IEs) compose beacon

- DEV are aware of DEVs located in one and two hop neighbourhood, defers from trying to reserve respective BSs

- Beacon Decoding Range is rather limited by noise than interference caused from data frame transmission
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ECMA-368: Medium Access Control
Data Transfer Period (DTP)

- User Data Frames are carried in reserved MASs negotiated previously.
- Management information on DRP controlled medium access is carried in Beacons.
- MASs are granted exclusively until DEV suspends DRPIE from Beacon transmission.
- DEVs not located in one-hop BG from owner or target may reuse MASs randomly for user data frame transmission.
- Maximum interference power is expected where Beacon Decoding Range covers same area \(^\text{[3]}\).

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## Scenario
### Description & Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Devs per ( m^2 )</td>
<td>( \rho = 0.05 \frac{DEVs}{m^2} )</td>
</tr>
<tr>
<td>DEV Position</td>
<td>Random uniform distributed</td>
</tr>
<tr>
<td>Pathloss Calculation</td>
<td>Mean Pathloss Channel Model (MPCM)</td>
</tr>
<tr>
<td>Mean Beacon Decoding Range</td>
<td>( r_{bg} = 16m )</td>
</tr>
<tr>
<td>Frequency</td>
<td>3.96GHz</td>
</tr>
<tr>
<td>Data Frame Size</td>
<td>1500B</td>
</tr>
<tr>
<td>Modulation and Coding Schemes (MCS)</td>
<td>53.3MB/s ... 480MB/s</td>
</tr>
<tr>
<td>Evaluated Scenarios Size</td>
<td>( r_s = n \cdot r_{gb} ) [ n = 1, 2, \ldots, 5 ]</td>
</tr>
<tr>
<td>Target FER</td>
<td>3%</td>
</tr>
<tr>
<td>Distance between owner and target, considered for MCS probability distribution</td>
<td>0.1m, ..., 9m</td>
</tr>
</tbody>
</table>
• Connectivity depends on number of DEVs located in the BG

\[
c_f = \sum_{i=1}^{N} \frac{M_i}{N(N-1)} = \frac{\rho \pi \cdot r_{bg}^2 - 1}{\rho \pi \cdot r_s^2 - 1} \approx \frac{r_{bg}^2}{r_s^2}
\]

connectivity \( c_f \), \( N \) number of DEVs located in scenario, \( \rho \) DEV density, \( M_i \) number of DEVs in one-hop BG neighborhood, \( r_{bg} \) Beacon Decoding Range, \( r_s \) evaluated scenario size

• Mean Number of DEVs located in BG

\[
N_{BG} = N \cdot c_f
\]

• Number of DEVs where first \( k = 1 \) co-channel interferer may occur

\[
N_{k=1} = (1 - c_f) \cdot N
\]

Analytical Study
Connectivity & Beacon Group

- Connectivity depends on number of DEVs located in the BG
  \[ c_f = \sum_{i=1}^{N} M_i / N(N - 1) = \frac{\rho \pi \cdot r_{bg}^2 - 1}{\rho \pi \cdot r_s^2 - 1} \approx \frac{r_{bg}^2}{r_s^2} \]
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Analytical Study
Number of DEVs able to Reuse MASs

- Number of DEVs where second $k = 2$ co-channel interferer may occur
  \[ N_2 = \bar{N}_2 + (N_1 - \bar{N}_2) \cdot c_f \]
  where $\bar{N}_2 = (1 - c_f)^2 \cdot N$

- Considers DEVs located in more than one BG
  \[ (N_1 - \bar{N}_2) \cdot c_f \]

- Leads in general to \[^{[4]}\]
  \[ N_k = N \left(1 - c_f\right)^{k+1} \]
  \[ + N_{k-1} c_f + \sum_{i=1}^{k-2} (N_i - N_{i+1}) c_f^{k-i} \]
  where $N_k$ states number of DEVs considered to calculate $k^{th}$ reuse of MASs

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Analytical Study
Probability of co-Channel Interferer

- Mean number of available MASs for DRP controlled user data frame transmission
  \[ \bar{d} = \frac{1}{N_{BG}} \sum_{i=0}^{N_{BG}-1} I_{MAS} - i \]

- Total number of available MASs in SF \( I_{MAS} = 256 \)

- Probability to find exactly \( k \) co-channel interferer
  \[ p_k = \binom{N_k}{k} \left( \frac{1}{\bar{d}} \right)^k \left( 1 - \frac{1}{\bar{d}} \right)^{N_{k+1}} \]
  \[ p_0 = 1 - \sum_{k=1}^{\infty} p_k \]

Results
Probability of Co-Channel Interferer

\[ r_k = 3 \cdot r_{bg} \]

\[ r_k = 4 \cdot r_{bg} \]

- Number of interfered DRP controlled user data frame transmissions is equivalent to MAS reuse in the scenario
- Probability that no DEV allocates MAS operated for user data frame transmission by another DEV decreases from 0.28 to 0.09 where radius \( r_k \) increases from \( 3 \cdot r_{bg} \) to \( 4 \cdot r_{bg} \)
- Monte Carlo experiment complies results obtained analytically
Results
Maximum Interference Power

- Interference power for increasing scenario size regarding parameter value $r_k = n \cdot r_{bg}$ with $n = 2, \ldots, 5$

- CDF tends to step function in scenarios where $r_k$ increases
- Concerning results DRP limits interference power to value $\approx -77dBm$
Results
MCS Probability Distribution & Achievable Throughput

- MCS probability results considers random distance between DRP reservation owner and DRP reservation from uniform distribution and constant interference power

- Achievable throughput concerning rate fair scheduling calculates from

\[ t_{hr} = \left( N_{BG} \cdot \sum_{i=1}^{7} \frac{p(MCS_i)}{rate_i} \right)^{-1} = 2.026 \frac{Mb}{s} \]

- Achievable throughput in Beacon Group is obtained from \( N_{BG} \cdot t_{hr} = 81.47 \frac{Mb}{s} \)
Conclusion:

- Interference power in UWB scenarios where DEVs operate DRP for user data frame transmission and allocate MAS randomly is limited to $-77\text{dBm}$

- Throughput achieved from DRP controlled medium access in densely populated network scenarios calculates to $81.47\frac{Mb}{s}\frac{1}{BG}$

Outlook:

- Apply Interference Aware Scheduling to gain throughput in UWB WPAN scenarios$^{[5]}$

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Thank you for your attention!

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