Effects of Pulsed Radar Waveforms on LTE (TDD) Receiver Performance

January 2014

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Background

- **FCC 3.5 GHz NPRM:**
  Calls for effects of pulsed radar signals on performance of LTE receivers to be investigated

- **NTIA / ITS action to date:**
  - Designed tests to demonstrate the effects of pulsed radar signals on the performance of LTE receivers
  - Worked with a carrier to perform tests in realistic conditions
  - Published results in an NTIA Technical Report (TR-14-499)
Test Design and Execution

- Develop a matrix of test waveforms
  - Types of radar signals in and around 3550-3650 MHz
    - Not specifically matched to any particular operational radars
    - Span the parameter range of existing and future radar systems in band
  - 2 Gaussian noise waveforms
  - Other waveforms used in previous ECC tests

- Work with a carrier to perform the tests
  - Inject radar waveforms into TDD 4G LTE base station receiver
  - Measure
    - Data throughput (handset to base station)
    - Block error rate
    - Receiver noise
**Radar Waveform Matrix**

**P0N (carrier wave) pulsed radar waveform parameters.**

<table>
<thead>
<tr>
<th>Duty Cycle (%)</th>
<th>PRR = 1000/sec</th>
<th>PRR = 3000/sec</th>
<th>PRR = 10,000/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>PW = 1 µs</td>
<td>PW = 0.33 µs</td>
<td>PW = 0.1 µs</td>
</tr>
<tr>
<td></td>
<td>P0N-1</td>
<td>P0N-2</td>
<td>P0N-3</td>
</tr>
<tr>
<td>1</td>
<td>PW = 10 µs</td>
<td>PW = 3.33 µs</td>
<td>PW = 1 µs</td>
</tr>
<tr>
<td></td>
<td>P0N-4</td>
<td>P0N-5</td>
<td>P0N-6</td>
</tr>
<tr>
<td>3</td>
<td>PW = 30 µs</td>
<td>PW = 10 µs</td>
<td>PW = 3 µs</td>
</tr>
<tr>
<td></td>
<td>P0N-7</td>
<td>P0N-8</td>
<td>P0N-9</td>
</tr>
<tr>
<td>10</td>
<td>PW = 100 µs</td>
<td>PW = 33.3 µs</td>
<td>PW = 10 µs</td>
</tr>
<tr>
<td></td>
<td>P0N-10</td>
<td>P0N-11</td>
<td>P0N-12</td>
</tr>
</tbody>
</table>

**Q3N (swept-frequency) pulsed radar waveform parameters, 1 MHz/µs chirp.**

<table>
<thead>
<tr>
<th>Duty Cycle (%)</th>
<th>Chirped Pulse Group 1</th>
<th>Chirped Pulse Group 2</th>
<th>Chirped Pulse Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PW (µs)</td>
<td>PRR (s⁻¹)</td>
<td>PW (µs)</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>1000 Q3N-1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>100 → 20</td>
<td>1000 → 200 Q3N-4</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>200 → 20</td>
<td>1000 → 100 Q3N-7</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>300 → 20</td>
<td>1000 → 67 Q3N-10</td>
<td>30 → 20</td>
</tr>
</tbody>
</table>
Radar Waveforms (continued)

- Interference waveform design overall goal: vary interference duty cycle (DC) values in an approximately logarithmic progression

- Chirp bandwidth of Q3N (chirped) pulses was an additional degree of freedom in the waveform design. Solution:
  - Hold chirp frequency-sweeping rate constant at 1 MHz /µs
  - Hold pulse widths to 20 µs
  - Full explanation and documentation in NTIA Technical Report TR-14-499

<table>
<thead>
<tr>
<th>Duty Cycle (%)</th>
<th>Waveform Names</th>
<th>PW (µs)</th>
<th>PRR (pulses/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>ECC-1 — WFM-1</td>
<td>4</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
<td>ECC-2 — WFM-2</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>.05</td>
<td>TDWR — P0N-13</td>
<td>1</td>
<td>500</td>
</tr>
</tbody>
</table>
Coupling Scenario

- Air search radars’ beams look slightly above the local horizons, coupling most strongly into base stations
- Test bed needed to replicate this coupling scenario

\[ \theta = \text{typically 0.5 to 1 angular degree (exaggerated here due to compression of this diagram's horizontal scale)} \]
Test Bed High-Level Schematic

LTE Base Station
- Tx
- Rx
- Base station receiver diagnostics
- Recording of LTE base station receiver performance diagnostics such as:
  - data throughput rate
  - block error rate
  - receiver noise level

Channel Emulator (optional)
- Two-way traffic (desired signal)
- Downlink
- Uplink
- RF Combiner

User Equipment (UE)
- Two-way traffic
- Downlink
- Uplink

Radar Interference Generator
- Radar interference (undesired signal)

Note: All connections are on RF hardlines.
• Radar signals isolated to only appear on base station receiver side of LTE system
• Diagnostic software monitored, recorded once every second:
  ▪ Data throughput
  ▪ BLER
  ▪ Receiver noise power
• 30 raw data points recorded per radar signal power level
Baseline Test State

- Handset → base station nominal data rate 16 Mbit/s with no radar signal present
- Handset power at base station receiver input = -83 dBm/180 kHz resource block, held constant throughout
- Radar signals not synchronized to any TDD time slots
- Not tested:
  - Call initiation and call hand-off
  - LTE receiver saturation and burnout levels
Baseline Test Methodology

- Un-modulated radar signals on-tuned with center frequency of the 20 MHz wide LTE channel
  - Chirp center on-tuned with the LTE center frequency
  - Chirp was low to high frequency, linear

- Radar signal power
  - Initiated at a low level
  - Increased in 4 and 10 dB steps to close to maximum permissible power set by the carrier's conditions
  - Pulsed radar signal continuously applied at each power level

- Data post processed to produce figures showing data throughput, BLER, and receiver noise level as a function of S/(I+N) for each radar waveform
Test Results

- NTIA is not specifying any particular acceptable radar signal power level for LTE receivers for the NPRM.

- NTIA work has only shown effects that can happen in the presence of radar signals:
  - Some radar waveforms had a drastic effect on the data throughput and caused the link to crash.
  - Some radar waveforms had moderate effects.
  - A few radar waveforms had no effect.
  - NTIA has not investigated why or how the effects are different.

- NTIA looks to the 4G LTE Industry to assist in analyzing the data and the results, and perhaps performing additional tests.
Example $S/(I+N)$: Extreme Effect on Throughput

Waveform P0N-10

$PW = 100\ \mu s$, $PRR = 1,000/sec$, $DC = 10\%$
Example $S/(I+N)$: Extreme Effect on Throughput
Waveform Q3N-5

$PW = 10 \ \mu s, \ PRR = 10,000/sec, \ DC = 10\%$
Example S/(I+N): Moderate Effect on Throughput
Waveform Q3N-6

PW = 3.3 μs, PRR = 30,000/sec, DC = 10%
Example S/(I+N): No Effect on Throughput
Waveform Q3N-7

PW = 20 µs, PRR = 100/sec
(equivalent to PW = 200 µs, PRR = 1,000/sec), DC = 20%
Future Work

NTIA looks forward to working with Industry on tests to:

- Test the authors’ hypothesis that similar tests on a micro-cell LTE system will yield similar results
- Theoretical analysis to better understand why various radar interference waveforms have particular effects
- Increase understanding of LTE signal detection and processing
- Determine the non-linear effects of saturation and front-end overload from radar signals on LTE receivers
- Determine effects of a variety of radar beam-dwell periods on LTE base station receivers by testing with bursts of pulses to simulate radar beam scanning or antenna rotation
References


References

https://sites.google.com/site/lteencyclopedia/lte-radio-link-budgeting-and-rf-planning


References


This Presentation