3.5GHz FNPRM
Model City PN

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Outline

• Radar to LTE Base Stations Interference Simulations
  • Background
  • Radar Basics
  • Prior Coexistence Work
  • Nokia Networks Simulations
  • Conclusions

• Model City
• LTE Synchronization
• Key Take-Aways

Note: Other 3.5GHz FNPRM topics like Spectrum Access System, Priority Access Licenses, Transmit Power, Emission Limits, GAA Floor, Contained Access Users, etc. are covered in details in various Nokia Networks’ filings with FCC and are not covered in this presentation
3.5GHz Radar Interference Effects on LTE Base Stations

Mo Ghorbanzadeh, Prakash Moorut, Eugene Visotsky
Disclaimer: Results presented hereafter are preliminary and will continue to be refined.

LTE Base Station Receiver non-linear effects of saturation and front-end overload from radar signals are for further study.
- National Telecommunications and Information Administration (NTIA) identified existing 3.5 GHz Federal operations.
  
  - Radiolocation systems: Includes Dept. of Defense (DoD) ground-based (GB), shipborne (SB), & airborne (AB) surveillance/tracking radars.
    
    • High-power surveillance measure targets altitude, range, and bearing at ranges as great as 300 nmiles.
    
    • Air Force assisting pilots in formation flying, drop-zone training
    
    • Weapon control systems (e.g. data update communications to missiles, gunfire control) in 3400 – 3650 MHz, air defense in 3100 – 3650 MHz.
  
  - Radionavigation systems: Includes Air Traffic Control (ATC), air marshalling, and short-range air-search radar systems.
    
    • Navy ship-borne radars operate in 21 channels throughout this band.

- Frequency relocating the above may require new technology and significant redesign.

- Radars increasingly operate over larger bandwidths to improve image resolutions as targets grow complex.
  
  - NTIA focused on geographic sharing leading to geographically-limited licensing.

- Adjacent band radars must be considered as they may pose an interference to the deployment of 3.5 GHz wireless systems.
  
  - Potential interference from in-band and adjacent radars might significantly limit how much spectrum is fully usable.
Radar Block Diagram

- Radars transmit high power pulses into outer space.
- Pulses undergo atmospheric, propagation, and system attenuation.
- Hitting an object, the pulse radiates in all directions (target acts as an omni source).
- The received pulses are at the same frequency as the radar pulses plus a Doppler shift.
- The received echo reveals a target is detected.
- Targets can be as far as 10000 km away (ballistic missile early warning system).
Radar Operating Parameters

• Operating Frequency: Carrier frequency within each pulse.

• Peak Power: Maximum pulse power.
  - Pulse energy is peak power multiplied by the pulse width (PW).

• Average power is peak power amplitude (PA) multiplied by duty cycle (pw/PRI).
  - Average energy in the pulse is average power multiplied by the duty cycle.

• Pulse Repetition Interval (PRI): Time between pulse arrivals.

• Rotation Speed: Complete horizontal scans in a minute.
  - Gives the horizontal scan time.

• Azimuth/Elevation (θA/θE) beamwidths relate to antenna diameters D as typically 75λ/D an gain as 33000/(θA×θE).

• Dwell time: Time antenna beam spends on a target & relates to θA and antenna rotation under non-track mode.
Interference Scenario

- 1- 10 GW peak effective isotropic power (EIRP) via tube type transmitters (TX)S.

- 10 - 100 MW EIRP via solid state TXs with longer PWs.
NTIA Fast Track Evaluation

An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz and 4380-4400 MHz Bands
Propagation Models

- **Airborne Radars**: Free Space propagation path loss LFS (dB) for central frequency \( f \) (MHz) & distance \( d \) (km) at line-of-sight (LoS) for interferer and victim antenna heights \( h_I \) and \( h_V \) in meters.

\[
L_{FS} = 20\log(f) + 20\log(d) + 32.45; d \leq 4.1(\sqrt{h_I} + \sqrt{h_V})
\]

- In the non-LoS (NLoS) region, a diffraction loss \( 0.62/\lambda \) dB/km is added (\( \lambda \sim 10\) cm for S band radars).

- **Ground Based and ShipBorne Radars**: Irregular Terrain Model (ITM), an improved version of Longley-Rice, predicts signal NLoS loss (median attenuation) in 20 MHz-20 GHz as a function of distance and signal temporal, location, and situation variability.

  - **Temporal variability** accounts for attenuation variability and can be short (due to fading) or long term (due to atmospheric and seasonal conditions such as snow, soil moisture, vegetation, and foliage) and expressed as 0.1 – 99.9%, time duration when received field strength is expected not to be less than the hourly median field.

  - **Location variability** describes the full range of signal levels over the small area and is based on antenna location changes, and expressed as 0.1 – 99.9%, fraction of locations where field strength is expected not be less than the median field strength.

  - **Situation variability** is a probability measure imposed on collection of all propagation paths. Expressed as 0.1 – 99.9%, it gives fraction of identical paths on which field strength is expected not be less than field computed by the program.
Interference Analysis

- Analyze TX -Radar (BS/MS)- interference into the receiver (RX) -BS/MS (Radar).
  - Interference threshold \( (I_T) \) between Federal & WiMAX for RX noise floor \( (N) \) in dBm, noise figure \( (F) \) in dB, and maximum permissible interference-to-noise ratio \( (I/N) \) in dB:
  \[
  I_T = \frac{I}{N} + N; \quad N = 10 \log(B_{IF}) + F - 114
  \]

- Interference threshold -6 dB (ITU-R M.1461-1), corresponding to 1 dB increase \( (\Delta) \) in RX effective noise.
  - I/N values 0, 3, 6, and 10 dB will be used in the interference analysis.

- **Radar to WiMAX Interference**: Below TX refers to radar and RX refers to WiMAX BS or MS.
  - Interference analysis determines minimum propagation path-loss \( L_{\text{min}} \) between radar TX & WiMAX RX to preclude interference.

\[
L_{\text{min}}\,\text{dB} = P_{T,dBm} + G_{T,\text{dBi}} + G_{R,\text{dBi}} - L_{T,\text{dB}} - L_{R,\text{dB}} + I_T - FDR_{dB}
\]

- \( L_{\text{min}} \) is used to determine the minimum separation distance, the radius for the germane exclusion zones.

- Interference occur if \( I = P_{T,dBm} + G_{T,\text{dBi}} + G_{R,\text{dBi}} - L_{T,\text{dB}} - L_{R,\text{dB}} - FDR_{dB} > I_T \)

- **WiMAX to Radar Interference**: For each WiMAX TX, interference is calculated & aggregate interference is the addition.

\[
I_j = P_{T,dBm} + G_{T,\text{dBi}} + G_{R,\text{dBi}} - L_{T,\text{dB}} - L_{R,\text{dB}} - FDR_{dB} \Rightarrow I_{\text{agg}} = 10 \log(\sum I_j) + 30
\]

- If \( I_{\text{agg}} > I_T \), interference occurs and the equality of the aggregate inference and threshold is the minimum separation distance, establishing exclusion zone radius.
### Table 5-2. Summary of Exclusion Zones, Ground-Based Radar Systems

<table>
<thead>
<tr>
<th>Radar to Wireless System Interaction</th>
<th>Ground-Based Radar – 1</th>
<th>Ground-Based Radar – 2</th>
<th>Ground-Based Radar – 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency Offset (MHz)</td>
<td>Radius of Exclusion Zone (km)</td>
<td>Frequency Offset (MHz)</td>
</tr>
<tr>
<td>Radar to Base (Single Entry)</td>
<td>50</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Radar to Mobile (Single Entry)</td>
<td>50</td>
<td>&lt;1</td>
<td>40</td>
</tr>
<tr>
<td>Base and Mobile to Radar (Aggregate)</td>
<td>50</td>
<td>24</td>
<td>40</td>
</tr>
</tbody>
</table>

### Table 5-3. Summary of Exclusion Zones, Airborne Radar Systems

<table>
<thead>
<tr>
<th>Radar to Wireless System Interaction</th>
<th>Airborne Radar – 1</th>
<th>Airborne Radar – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency Offset (MHz)</td>
<td>Exclusion Zone Distance (km)</td>
</tr>
<tr>
<td>Radar to Base (Single Entry)</td>
<td>40</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Radar to Mobile (Single Entry)</td>
<td>40</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Base and Mobile to Radar (Aggregate)</td>
<td>40</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

### Table 5-4. Summary of Exclusion Zone Distances, Shipborne Radar Systems

<table>
<thead>
<tr>
<th>Radar Identifier</th>
<th>Radar to Wireless Broadband System Interaction</th>
<th>Radar to Base (Single Entry)</th>
<th>Radar to Mobile (Single Entry)</th>
<th>Base/Mobile to Radar (Aggregate)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geographic Area</td>
<td>Exclusion Zone Distance (km)</td>
<td>Exclusion Zone Distance (km)</td>
<td>Exclusion Zone Distance (km)</td>
</tr>
<tr>
<td>Shipborne Radar – 1</td>
<td>East Coast</td>
<td>361</td>
<td>68</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>West Coast</td>
<td>443</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gulf Coast</td>
<td>339</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipborne Radar – 2</td>
<td>East Coast</td>
<td>134</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>West Coast</td>
<td>235</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gulf Coast</td>
<td>105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipborne Radar – 3</td>
<td>East Coast</td>
<td>224</td>
<td>47</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>West Coast</td>
<td>286</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gulf Coast</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipborne Radar – 4</td>
<td>East Coast</td>
<td>448</td>
<td>143</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>West Coast</td>
<td>404</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gulf Coast</td>
<td>438</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipborne Radar – 5</td>
<td>East Coast</td>
<td>435</td>
<td>309</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>West Coast</td>
<td>415</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gulf Coast</td>
<td>537</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The exclusion zone distance is based on the maximum value. The detailed terrain dependent exclusion zone distances are provided in Appendix E.
WiMAX-Shipborne Radar Exclusion Zones
Comments

• The exclusion zones are extracted from link budget analysis of radar-WiMAX systems.

• NTIA: Any changes to the involved system can change the obtained exclusion zones.

• LTE will be one of the predominant cellular technologies in the 3.5 GHz band.

• Exclusion zones based on LTE deployments need to be studied.
Nokia Networks Simulations

Radar Interference into LTE Macro and Small Cells Base Stations
Radar Simulation

- Radar parameters in the table are adopted from NTIA’s Fast Track Report\(^1\).

- Radar radiates on LTE at 50, 100, 150, and 200 km away.

- 83 dBm without antenna, and 83 + 45 = 128 dBm EIRP.

- 360 deg horizontal scan.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>3.5 GHz(^*)</td>
</tr>
<tr>
<td>Peak Power</td>
<td>83 dBm</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>45 dBi</td>
</tr>
<tr>
<td>Antenna Pattern</td>
<td>Cosine</td>
</tr>
<tr>
<td>Antenna Height</td>
<td>50 m</td>
</tr>
<tr>
<td>Insertion Loss</td>
<td>2 dB</td>
</tr>
<tr>
<td>Pulse Repetition Interval</td>
<td>0.5 ms</td>
</tr>
<tr>
<td>Pulse-Width</td>
<td>78 μs</td>
</tr>
<tr>
<td>Rotation Speed</td>
<td>30 rpm(^*)</td>
</tr>
<tr>
<td>Azimuth Beam-Width</td>
<td>0.81 deg(^*)</td>
</tr>
<tr>
<td>Elevation Beam-Width</td>
<td>0.81 deg(^*)</td>
</tr>
<tr>
<td>Azimuth Scan</td>
<td>360 deg</td>
</tr>
<tr>
<td>Distance to LTE</td>
<td>50, 100, 150, 200 km</td>
</tr>
</tbody>
</table>

\(^1\)An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz and 4380-4400 MHz Bands\(^*\)
NTIA, U.S. Dept. of Commerce, Nov. 2010
Radar Simulation

- Radar circulates at 30 rotation per minute (rpm).
  - Horizontal scan time becomes 2 s.
  - $\frac{360}{0.81} = 445$ beam positions for the search fence.
  - Antenna dwell time becomes $\frac{2}{445} = 4.5$ ms.
  - PRI = 0.5 ms gives 9 pulses during the dwell time.
  - An BS under radiation is hit by 9 pulses.
  - 4000 pulses (each 83 + 45 dBm) are radiated in a rotation of the antenna.

- At distance $R$ radar radiation diameter becomes:

$$d = 2R \tan (\theta_a) \approx 0.03R$$

  - 1.5, 3.0, 4.5, 6.0 km radiation diameter when radar is 50, 100, 150, and 200 km away.
Radar Simulation

• Antenna back-lobe -50 dB vs. the main lobe.

• Based on ITU-R M.1851 (mathematical model for radar antenna used in NTIA Fast Track Report).

\[
G(\theta) = \begin{cases} 
\pi \left( \frac{\cos \left( \frac{68.8\pi \sin(\theta)}{\theta_{3dB}} \right)}{\frac{\pi}{2}} \right) - \left( \frac{68.8\pi \sin(\theta)}{\theta_{3dB}} \right)^2 \\
-17.51 \log_e \left( \frac{2.33 |\theta|}{\theta_{3dB}} \right) \\
-50 \text{ dB}
\end{cases}
\]
LTE Simulation (Macros, Outdoor Small Cells)

**Antenna Pattern for Macro LTE BS**

\[
G_i(\theta_i) = \min \{ \left| 2 \left( \frac{\theta_i - \theta_{i,i}}{\theta_{3dB}} \right)^2 \right|, A_m \}, \ i \in \{ A, E \} \quad \text{and} \quad G = - \min \{ - (G_A(\theta_A) + G_E(\theta_E)), A_m \}
\]

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- **Parameters**
- **Value**
  - Operating Frequency: 3.5 GHz
  - Layout: Hexagonal macro cell grid, clustered small cells
  - Mode: TDD
  - Macro/Small Cells BS TX Power: 46/30 dBm
  - UE Transmit (TX) Power: 23 dBm
  - Macro-cell sites/cells: 7/21 (3 cells per site)
  - Small cells: 84 (4 per macro cell)
  - Indoor UE ratio for Macro / Small cells: 80% / 20%
  - Bandwidth for Macro / Small cells: 20 MHz
  - BS Antenna Gain for Macro / Small cells: 17/5 dBi
  - UE Antenna Gain: 0 dBi
  - Macro Inter-site Distance (ISD): 500 m
  - Minimum UE-BS Distance for Macro / Small cells: 25 / 5 m
  - BS Antenna Downtilt for Macro: 12 deg
  - BS Antenna for Small Cells: Omni-directional
  - BS Antenna Height: 25 (macro), 10 (outdoor small cells)
  - UE Antenna Height: 1.5 m
  - UE Distribution for Macro / Small cells: Uniform/Clustered
  - UE Mobility: 3 km/h, uniform direction
  - BS/UE Noise Figure (NF): 5/9 dB
  - Thermal Noise: -174 dBm/Hz
  - Service Profile: Full buffer best effort
  - UEs per Cell for Macro / Small cells: 10 / 30
  - Channel Model for Macro / Small cells: UMa / UMi [1]

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UMa = Urban Macro
UMi = Urban Micro
# LTE Simulation (Indoor Small Cells)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>3.5 GHz</td>
</tr>
<tr>
<td>Layout</td>
<td>Indoor hall</td>
</tr>
<tr>
<td>Mode</td>
<td>TDD</td>
</tr>
<tr>
<td>BS TX Power</td>
<td>30 dBm</td>
</tr>
<tr>
<td>UE Transmit (TX) Power</td>
<td>23 dBm</td>
</tr>
<tr>
<td>Indoor Small cells</td>
<td>2</td>
</tr>
<tr>
<td>Indoor UE</td>
<td>100%</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>BS Antenna Gain</td>
<td>5 dBi</td>
</tr>
<tr>
<td>UE Antenna Gain</td>
<td>0 dBi</td>
</tr>
<tr>
<td>BS Antenna</td>
<td>Omni-directional</td>
</tr>
<tr>
<td>BS Antenna Height</td>
<td>6 m</td>
</tr>
<tr>
<td>UE Antenna Height</td>
<td>1.5 m</td>
</tr>
<tr>
<td>UE Distribution</td>
<td>Uniform</td>
</tr>
<tr>
<td>UE Mobility</td>
<td>3 km/h, uniform direction</td>
</tr>
<tr>
<td>BS/UE Noise Figure (NF)</td>
<td>5/9 dB</td>
</tr>
<tr>
<td>Thermal Noise</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Service Profile</td>
<td>Full buffer best effort</td>
</tr>
<tr>
<td>UEs</td>
<td>20 (10 per indoor small cell)</td>
</tr>
<tr>
<td>Channel Model for Small cells</td>
<td>InH[1]</td>
</tr>
</tbody>
</table>

InH = Indoor Hot Spot

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LTE System Simulation Model

• 3GPP-compliant system-level simulator.
• 3GPP-defined macro, small-cell and indoor scenarios.
• Utilizes proportional-fair scheduler in both time and frequency domains.
• Detailed UL air interface modeling, UL MIMO, and receiver diversity.
• Non-ideal link adaptation with Hybrid ARQ and Exponential Effective SINR Mapping (EESM) link-to-system mapping.
LTE Model Enhancements From Nokia’s FNPRM Filings

• Modeling RF receiver saturation threshold
• More precisely modeling Turbo decoder saturation
• Updated SC-OFDMA SINR calculation with radar interference present
• Explicitly using pilot symbols for Base Stations interference measurements
• Macro cell layout for 7 sites.
• 500 m ISD.
Outdoor Small Cells Layout

Macro and Small Cell Layout

- Pico cell
- UE
- Macro cell
For an UE at a distance $R$ (km) from the LTE BS:
- $\text{PL}_{\text{LoS}} = 89.5 + 16.9 \log (R)$
- $\text{PL}_{\text{NLoS}} = 147.4 + 43.3 \log (R)$

The LoS probability is:

$$
\begin{align*}
&\begin{cases} 
1 & R \leq 0.018 \\
\exp(-0.018/0.027) & 0.018 < R < 0.037 \\
0.5 & R \geq 0.037 
\end{cases} 
\end{align*}
$$
Propagation Models (radar-LTE path)

- In LoS, FSPL represents the loss radar signal undergoes.

\[ L_{dB,FSPL}(r) = 20\log(f) + 20\log(r) + 32.45, r < r_{LoS} \]

\[ r_{LoS} = 4.1(\sqrt{h_{radar}} + \sqrt{h_{LTE}}) \]

- In NLoS region, ITM model represents the loss.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Mode</td>
<td>Area Prediction Mode</td>
</tr>
<tr>
<td>Small, Macro cells LTE/Radar Antenna Height</td>
<td>10, 25/50 m</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>15</td>
</tr>
<tr>
<td>Conductivity</td>
<td>0.005 S/m</td>
</tr>
<tr>
<td>Refractivity</td>
<td>301 N-units</td>
</tr>
<tr>
<td>Climate</td>
<td>Continental Temperate</td>
</tr>
<tr>
<td>Variability Mode</td>
<td>Single Message</td>
</tr>
<tr>
<td>Surface Refractivity</td>
<td>15</td>
</tr>
<tr>
<td>Sitting Criteria</td>
<td>Random</td>
</tr>
</tbody>
</table>

![Graph showing propagation loss vs distance](image.png)
Simulation Results (Macro Cells)

- Signal-to-interference-to-noise ratio (SINR) of an LTE BS versus LTE symbol and subcarrier indices.
  - Even when radar is present, SINR recovers until next pulse.
  - Radar pulse is centered in the LTE band, so most energy is concentrated around subcarrier 300 (middle of the LTE channel).
  - 78 μs wide pulses exceed the duration of the LTE symbol (71.4 μs).
  - Energy is mostly concentrated in symbols 1 and 8, with some remaining pulse energy also present in symbols 2, 9 and 14.
Simulation Results (Macro Cells-UMa)

- Normalized Throughput.
Simulation Results (Outdoor Small Cells-UMi)

• Normalized Throughput.
Simulation Results (Indoor Small Cells-InH)

- Normalized Throughput.
Simulation Results (Comparison of indoor/outdoor/macros)

- Macro Cells
- Outdoor Small Cells
- Indoor Small Cells

Normalized Throughput

- 50 km
- 100 km
- 150 km
- 200 km
- Baseline
Simulation Results (Out of Band)

- Radar at 50 km, 10MHz LTE.
- Radar operating at frequency offsets from the LTE frequency.
Conclusions

• The exclusion distances between radars and LTE in NTIA Fast Track Report are overly conservative
  • Need to accurately model the radar and LTE systems.

• Need to better characterize the propagation characteristics between radars and LTE
  • One option: Model City (see later)

• On-going/Future work includes:
  • Downlink (radar to LTE UEs interference)
  • RF saturation and burnout
  • Interference mitigation and avoidance
  • LTE to radar interference

• Premature to lock in large exclusion zones
  • What is FCC’s timeline?
  • Will there be opportunities for reconsideration even after initial rules (e.g., to decrease zones further, allow LTE deployments inside exclusion zones, i.e., convert to coordination zones, etc)?
Model City

Prakash Moorut, Joseph Schuler
Model City (1/2)

- Existing commercial propagation models (e.g., used in 3GPP) and models used by government (e.g., Irregular Terrain Model) may not be appropriate for the sharing scenarios considered
  - Recognized as part of CSMAC Working Groups on 1695-1710MHz and 1755-1850MHz

- One significant value to the Model City program could be in conducting the measurements required to develop various propagation models for anticipated commercial deployment scenarios in a shared context with government users
  - Can be cooperative arrangement among public and private companies, industry interest groups and standards organizations, universities and U.S. Government agencies such as NTIA among others.
Model City (2/2)

- Defining a propagation model is not an easy task.
- Examples can be found in Europe through such activities as the WINNER program.
  - Such programs have been funded in part through European Research programs such as FP7, formally known as the 7th Framework Program for Research and Technological Development, and more recently through the new HORIZON 2020 program.

References:

http://www.ist-winner.org/index.html
http://ec.europa.eu/research/index.cfm
http://ec.europa.eu/programmes/horizon2020/
One possible Model City Funding model

- Consider some form of funding from sources other than just private industry.
- The European Union funded programs could serve as a possible framework to provide a similar model in the U.S. either through supportive funding from entities such as the National Science Foundation, the U.S. Department of Commerce or other means.
  - This is not to suggest that all funding be government provided
  - Rather, we seek to augment the significant resources already being spent by industry to meet the ever increasing and difficult challenges of finding reasonably low cost and meaningful solutions to the spectrum sharing problem and we would expect that industry and affected Government entities such as the U.S. Department of Defense and similar agencies impacted by the spectrum sharing topic would contribute some of their internal R&D funding and other resources toward addressing the problem.
EU 7th Framework Programme (FP7) Work programme 2013

- Last round of FP7: calls accounting for around €8bn
- Strong Horizon 2020 flavour
  - Clear priorities/challenges
  - More innovation
  - Piloting new approaches

Wireless World Initiative New Radio (WINNER)

• Consortium of 41 partners coordinated by Nokia Networks working towards enhancing the performance of mobile communication systems.
  - Channel models used in 3GPP evaluation
  - SPECULATOR" for estimating the spectrum requirements for the future development of IMT-2000 and IMT-Advanced.

• Completed in 2007.

• Follow-on project WINNER+
EU Horizon 2020

- European Commission proposal for a 80 billion euro research and innovation funding program (2014-2020)

- A core part of Europe 2020, Innovation Union & European Research Area:
  
  - **Responding to the economic crisis** to invest in future jobs and growth
  
  - **Addressing people’s concerns** about their livelihoods, safety and environment
  
  - **Strengthening the EU’s global position** in research, innovation and technology

5G Public Private Partnership (www.5g-ppp.eu)
Part of Horizon 2020 program

**Timeline**

- 5G PPP industry launch at MWC2014
- Submission deadline of proposals on November 25, 2014
- Project start first half of 2015

**Funding**

€700 mn
Public funding (EU) shared between many 5G-PPP projects
5G-PPP How to start a project?

Major steps

- EU Commission publishes open Call for Proposals
- Proposal preparation
  - In minimum 3 partners from
  - in minimum 3 EU countries
  - Open for international cooperation
- Proposal submission at fixed deadline
- Proposal evaluation by independent evaluators
- Grant agreement to successful consortia

Openness and transparency
Conclusions

• Some form of funding from sources other than just private industry
  - Consider the EU funding model as framework.

• One goal could be to conduct the measurements required to develop various propagation models for anticipated commercial deployment scenarios in a shared context with government users.
LTE Synchronization

Introduction

• Sync Requirements and Alternatives
• Flexi Zone Micro, Pico Synchronization
• IEEE1588v2 – Key Components in 1588v2 System
• Future: Radio Interfaced Based Synchronization (RIBS)

August 29th 2014
Larry D. Svec
Small Cell Technology and Architecture Group
## Simplified Summary of Sync Requirements and Synchronization Alternatives

<table>
<thead>
<tr>
<th>RAT</th>
<th>Features</th>
<th>Freq Sync</th>
<th>Time/phase sync</th>
<th>Suitable Sync Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>Without DFCA</td>
<td>±50 ppb</td>
<td>No requirement</td>
<td>GPS, SyncE, 1588/ToP</td>
</tr>
<tr>
<td></td>
<td>DFCA - Dynamic Freq and Chan Allocation</td>
<td>±50 ppb</td>
<td>±9 μs</td>
<td>GPS, 1588/ToP with phase with no on-path or partial on-path support</td>
</tr>
<tr>
<td>WCDMA</td>
<td>All features</td>
<td>±50 ppb</td>
<td>No requirement</td>
<td>GPS, SyncE, 1588/ToP</td>
</tr>
<tr>
<td>LTE TDD</td>
<td>Basic LTE TDD Operation</td>
<td>±50 ppb</td>
<td>±1.5 μs</td>
<td>GPS, 1588/ToP with phase with partial or full on-path support</td>
</tr>
<tr>
<td>LTE FDD</td>
<td>Basic FDD All except specific features below</td>
<td>±50 ppb</td>
<td>No requirement</td>
<td>GPS, SyncE, 1588/ToP with Frequency with no or partial on-path support</td>
</tr>
<tr>
<td></td>
<td><strong>Low accuracy phase:</strong></td>
<td>±50 ppb</td>
<td>±10 μs</td>
<td>GPS, 1588/ToP with phase with no on-path support or partial on-path support</td>
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<tr>
<td></td>
<td>IRC (Interference Rejection Combining)</td>
<td></td>
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<tr>
<td></td>
<td><strong>High accuracy phase:</strong></td>
<td>±50 ppb</td>
<td>±2 μs to ±3 μs</td>
<td>GPS, 1588/ToP with phase with partial or full on-path support</td>
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<tr>
<td></td>
<td>eICIC</td>
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<tr>
<td></td>
<td>CA Carrier Aggregation</td>
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<td></td>
<td>Inter eNB CoMP DL except JT</td>
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<tr>
<td></td>
<td>Inter eNB CoMP UL with J R MBMS</td>
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<td></td>
<td>Coordinated Scheduling/Beamforming (CS/CB)</td>
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<tr>
<td></td>
<td><strong>Very high accuracy phase:</strong></td>
<td>±5 ppb</td>
<td>±0.3 μs to ±0.5 μs</td>
<td>GPS, 1588/ToP with phase with full on-path support</td>
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<tr>
<td></td>
<td>Inter eNB CoMP DL with J T</td>
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</tr>
</tbody>
</table>
Flexi Zone Micro, Pico Synchronization

Flexi Zone Synchronization provides CAPEX & OPEX savings by eliminating additional HW to provide reliable synchronization

**GPS**
- Integrated GPS Receiver with a phase accuracy of 50ns
- Support nLOS GPS reception (Urban canyons, limited in-building)
- Detachable GPS antenna to support remote positioning
- Support of Multi-GNSS (GPS/GLONASS)

**SyncE**
- Ethernet Phy/MAC HW recovered clock used as freq reference
- FPGA time stamps recovered SyncE clock - SW processing of Synch Status Message (ESMC, SSM)

**1588v2**
- Pkt based UDP/IP PTP protocol according to IEEE1588v2
- Uses time stamped messages to synchronize Flexi Zone Micro clock to PRC traceable master clock
- Support of both Freq & Time/Phase clock reference

**FPGA**
- Time stamps recovered SyncE clock - SW processing of Synch Status Message (ESMC, SSM)

**SyncE**
- 1588v2
- Frequency, Time, Phase

**GPS**
- Frequency, Time, Phase

**GPS**
- Frequency, Time, Phase

**SyncE**
- Frequency

**1588v2**
- Frequency, Time, Phase

**1588v2**
- Frequency, Time, Phase
IEEE1588v2 – Key Components in 1588v2 System

An IEEE1588v2 “Synchronization System” has 3 main components:

- **GMC**: The IEEE1588v2 “Grand Master Clock” (GMC) which provides the necessary 1588v2 message exchanges with the Client clock nodes in the network.

- **Client**: The cell sites with the IEEE1588v2 “Client Clock” hardware and software (IEEE1588v2 Client is sometimes also referred to as a IEEE1588v2 slave node).

- **Transport**: The IEEE1588v2 compliant transport network that connects the above elements.
Nokia recommends deploying the Grand Master Clock (GMC) as close to the APs as possible e.g. “On-Campus”
IEEE1588v2 High Level Theory of Operation

“Simplified Version”:

1. Master clock sends 1588v2 synchronization packets with time stamps to all Client clocks.

2. Each eNB Client clock responds back to the master clock with a time stamped response message.

3. Master establishes a separate synchronization session with each of the Clients in it’s time synchronization domain.

4. The Client clocks use this time delay information obtained from the round trip message exchange with the master clock to help create the master time.

5. The Client clock software algorithms must account for delays, jitter, and other transport related impacts to the round trip messages.

6. This message exchange between the master and Clients occurs periodically to both maintain and to refine the accurate time synchronization at the eNB Client clock. *(typically 15 to 60 times per second).*
Radio Interfaced Based Synchronization (RIBS)  *** 3GPP RELEASE-12 ***

Macro (w/GPS) as Synchronization Source
(Macro is “Stratum 0 Reference”)

- Supplement to GPS and 1588v2 – use RIBS mainly when GPS and 1588 are not practical
- Mainly targeted at indoor deployments (outdoor usually uses GPS)
- FDD, TDD: Frequency Reference
- TDD: TX/RX timing and frame alignment
- Supports most but not all LTE Advanced Services

Pico (w/GPS) as Sync Source
(Small Cell 1 is “Stratum 0 Reference”)
Conclusions

- Multiple methods available to provide Frequency, Time, and Phase sync for LTE
  - Use GPS whenever it is practical (outdoors, or indoors with external antenna)
  - Use IEEE1588 for larger in-building deployments
  - Future LTE Radio Interface Based Synchronization (aka “RIBS” or Listen Mode) provides an indoor alternative to GPS & 1588

- Adjacent LTE-TDD Operator Synchronization
  - If no guard band,
    - Ideally operators should align with common TDD TX/RX ratio
    - And Operators should be TX/RX Phase aligned
  - Otherwise inter-operator interference could occur
Key Take-Aways

• 3.5GHz FNPRM
  - Still some open issues
  - Premature to lock in large exclusion zones
  - Allow operation inside exclusion zones (coordination zones).
  - FCC’s timeline and approach? Opportunities to evolve rules?

• Model City
  - Include field measurements for propagation characterization
  - Consider EU funding model as a framework

• LTE Synchronization
  - Multiple methods available to provide Frequency, Time, and Phase sync for LTE
  - Adjacent LTE-TDD Operator Synchronization