WiFi and LTE coexistence management and capacity gain - Setting the scene

CW Technology and Engineering Conference
Integrate or differentiate? - The future of mobile, satellite, TV, IOT and wearable technology and its impact on spectral value
24th March 2015
PwC LLP, 7 More London Riverside, London, SE1 2RT
HISTORY'S FIRST WIRELESS SIGNAL INTERFERENCE
Why co-exist?

Co-existence is necessary when demand for a finite resource needs to be shared between users.

Without effective co-existence measures, wireless communications degrade or fail due to interference.

There is a large body of work dedicated to interference cancellation (IC) which cleans up the mess from non-ideal co-existence measures.

- IC often offers useful gains but can only go so far before suffering from diminished returns.

Of more fundamental significance to wireless performance are the techniques available for interference avoidance.
## Co-existence domains for interference avoidance

<table>
<thead>
<tr>
<th>Co-existence domain</th>
<th>Pros</th>
<th>Cons</th>
<th>Future Capacity Growth Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Simple multiple access method: My slot then your slot</td>
<td>No capacity gain</td>
<td>0</td>
</tr>
<tr>
<td>Frequency</td>
<td>Simple capacity gain: My frequency and your frequency</td>
<td>Expensive: Spectrum licensing costs and hardware impact.</td>
<td>&lt;6 GHz: ~2x 6 - 90 GHz: 10x? Depends on WRC15/19</td>
</tr>
<tr>
<td>Code</td>
<td>Simple multiple access method: My code and your code</td>
<td>Limited by SINR No capacity gain</td>
<td>0</td>
</tr>
<tr>
<td>Eigen modes (MIMO spatial multiplexing)</td>
<td>Capacity gain possible in high SINR semi-static environments</td>
<td>Limited by SINR and antenna performance. Hardware impact.</td>
<td>0.5x (excluding massive MIMO)</td>
</tr>
<tr>
<td>Polarization</td>
<td>Always available</td>
<td>Underused (elliptical)</td>
<td>~2x to ~4x?</td>
</tr>
<tr>
<td>Space</td>
<td>It’s free and there are huge quantities of it!</td>
<td>High cell count with h/o &amp; backhaul needs</td>
<td>100x – 1000x</td>
</tr>
</tbody>
</table>
Space: The final frontier - but also the first frontier where the need for co-existence was first discovered

Complaints about interference between transmitters of the first Marconi maritime radio system in the North Atlantic directly led to the later introduction of the first interference avoidance mechanism of frequency selection.

Until then, it was estimated that the earth could support only eleven cells!
The impact of spatial re-use on data densities

<table>
<thead>
<tr>
<th>Cell Type Attribute</th>
<th>Iridium Satellite</th>
<th>Rural</th>
<th>Urban macro</th>
<th>Urban micro</th>
<th>Pico</th>
<th>Femto</th>
<th>Wi-Fi Hotspot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage</td>
<td>Worldwide (outdoor)</td>
<td>Rural</td>
<td>Urban</td>
<td>Urban</td>
<td>Metro</td>
<td>Home/Metro</td>
<td>Home/Metro</td>
</tr>
<tr>
<td>Mobility</td>
<td>Perfect</td>
<td>V Good</td>
<td>V Good</td>
<td>Good</td>
<td>Fair</td>
<td>Nomadic</td>
<td>Nomadic</td>
</tr>
<tr>
<td>Cell radius</td>
<td>1500 km</td>
<td>30 km</td>
<td>3 km</td>
<td>300 m</td>
<td>30 m</td>
<td>10 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Cell area km²</td>
<td>7,700,000</td>
<td>2826</td>
<td>28</td>
<td>0.28</td>
<td>0.0028</td>
<td>0.0003</td>
<td>0.0003</td>
</tr>
<tr>
<td>Total cells</td>
<td>66</td>
<td>500 k</td>
<td>1 M</td>
<td>5 M</td>
<td>50 M</td>
<td>500 M</td>
<td>1 B</td>
</tr>
<tr>
<td>Total System capacity/MHz</td>
<td>40 Mbps</td>
<td>500 Gbps</td>
<td>1 Tbps</td>
<td>7.5 Tbps</td>
<td>75 Tbps</td>
<td>1500 Tbps</td>
<td>1000 Tbps</td>
</tr>
<tr>
<td>Capex/cell</td>
<td>$5 M</td>
<td>$250 k</td>
<td>$200 k</td>
<td>$50 k</td>
<td>$5 k</td>
<td>$200</td>
<td>$50</td>
</tr>
<tr>
<td>Opex/cell/year</td>
<td>$700 k</td>
<td>$25 k</td>
<td>$20 k</td>
<td>$10 k</td>
<td>$5 k</td>
<td>$50</td>
<td>$20</td>
</tr>
<tr>
<td>Efficiency bps/Hz</td>
<td>0.6</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
<td>3</td>
<td>1 – 2.5</td>
</tr>
<tr>
<td>Data density Mbps/km²/MHz</td>
<td>0.000000008</td>
<td>0.00035</td>
<td>0.035</td>
<td>3.5</td>
<td>350</td>
<td>10000</td>
<td>3000</td>
</tr>
</tbody>
</table>

Spectral efficiency almost static, data density varies 125 Billion : 1
Extending the spatial domain at mmWave

At lower frequencies signals are more omnidirectional and so cells need to be physically separate in order not to interfere

- This means that for any given spectrum, cell size defines the capacity of any area

At mmWave, frequency-dependent path loss is high but antennas are small so path loss can be overcome using high gain arrays

High gain arrays create narrow beam patterns that can also be steered to exploit the spatial domain within the cell area
Increasing mmWave capacity through co-located cells

mmWave narrow beam widths enable cells to get closer or even co-locate.
This could be described as increased cell count or increased area spectral efficiency depending the perspective.

A more advanced approach is to implement massive MIMO from a single cell which enables coordinated beamforming across UEs.
Co-location vs. Massive MIMO

With today’s technology, the potential gains from Massive MIMO are probably of a similar magnitude to the difficulty in making affordable solutions.

The approach of co-locating or closely locating simpler single link radios for similar performance gains is therefore attractive:

- Beamforming coordination (null steering) across multiple users would not be possible.
- However co-location has already been demonstrated using 802.11ad with linear scaling of cost and complexity.

In the meantime research into Massive MIMO continues.

The added challenges beyond 802.11ad of mobility and outdoor environments that don’t have rich scattering are considerable.
Massive MIMO tutorial

For a more in-depth discussion of Massive MIMO see:

Massive MIMO and mmWave Technology Insights and Challenges

To date, massive MIMO research has been largely theoretical, and with much of the published work in a form that is either unapproachable by the average engineer or so overly simplified as to be unhelpful. This presentation strives to provide an intuitive understanding of massive MIMO technology and its challenges, while taking care to completely avoid the math. Included will be a demonstration on the qualitative impact of channel characteristics on power amplifier requirements.

Presented by: Bob Cutler, Senior Solution Architect, Keysight Technologies
Increasing mmWave capacity with Massive MIMO

The four beam patterns below are simultaneously transmitted to separate UE from a 50 element linear array of omnidirectional elements at $\frac{1}{2} \lambda$ spacing.
Complete mmWave transceiver on a Chip

- 12 antenna per Tx and Rx chain
- 1.76 GHz of bandwidth
- Element control with 2 bit phase shifters (90° resolution)
- Centre frequency of 60.48 GHz or 62.64 GHz (802.11ad channels 2 or 3)
- 18 dBi additional beamforming gain
mmWave beamforming measurements
mmWave beamforming measurements
mmWave Flexible Backhaul at Bristol in Open www.bristolisopen.com
Demonstration of 72 closely located mmWave transceivers

https://www.youtube.com/watch?v=4M4ngJsQF70

Approximately 3 Gb/s/m² – about 1000x RF cellular density!

36 bi-directional links in an area of 30 m²

Simultaneous file transfer and video streaming with an aggregate data rate of 100 Gb/s

So with this much performance do we need massive MIMO?
The future is already here, it’s just not evenly distributed.
William Gibson

Thank you for listening!