Frequency, Time, and Phase in the 3.5 GHz CBRS Band

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Agenda

- CBRS Band Description
- Timing in CBRS
- Experiences over the last year

New approach to allocating spectrum resources

Frequency, time, and phase are important

Lessons learned...

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Google’s Mission Statement

Organize the world’s information and make it universally accessible and useful.

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Traditional Spectrum Licensing

- Spectrum purchasing (perpetual license)
- Covers large swathes of area
- Expensive $B

- Results:
  - Large barriers to entry
  - Purchase resources based on projected future needs
  - Resources are unused until those needs materialize

Industry Initiative to Improve Spectrum Access

- President's Council of Advisors on Science and Technology (PCAST) report
- "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth"
  - Published in July 2012
  - http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf
- Co-authored by a large group of individuals including Eric Schmidt from Google.
- FCC R&O #1 released April 2015
  - https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-47A1.pdf
- FCC R&O #2 released May 2016
  - https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-55A1.pdf

https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports

3.5 GHz Spectrum

- 150 MHz of spectrum from 3.55 GHz to 3.7 GHz
- “Lightly used”
  - US Navy uses it for SPN-43 non-combat, aircraft carrier landing radar
    - 1.6 MHz BW
    - 1 MW RF power conducted
    - 1.6 GW EIRP (enough for time travel!)
  - Satellite industry (Rx Only)
  - Wireless ISP’s (WISP)

CBRS Band

- CB radio is back!
- Citizen’s Broadband Radio Service (CBRS)
- Shared spectrum
- 3 Tiers of usage rights
  1. Incumbents
  2. Primary Access License (PAL)
  3. General Authorized Access (GAA)

Tier 1: Incumbents

- US Navy
  - Absolute priority over anyone else
  - “We’re here. We want this frequency. Get off. <EOM>”
- Fixed Satellite Services (FSS)
  - RX only
- Wireless ISP’s
  - Must migrate to CBRS by 2020

Tier 2: PAL

- Groups/ entities that have purchased a CBRS PAL license
- License lasts for 3 years
- Covers a single census tract
- If a PAL license is not being used, it can be used by a GAA device
- Guaranteed clean access to spectrum
  - Must not interfere with incumbents

Census Tracts (Lower Manhattan)

Census Tracts (SF and surrounding)

tigerweb.geo.census.gov/tigerweb

Tier 3: GAA

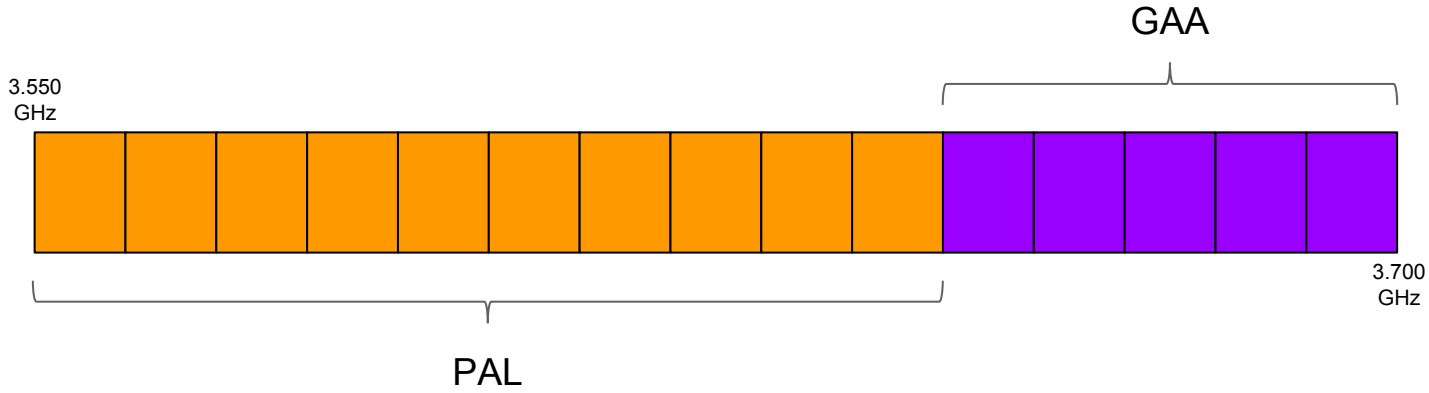
- Everybody else
- No guarantees
- Anybody can use spectrum*
  - Must use CBRS certified device
  - Must register and be controlled by SAS
  - Must not interfere with PAL or Incumbent

- No coordination is provided among GAA devices

SAS - Spectrum Access System

- Before transmitting, Citizens Broadband Service Device (CBSD) must contact the SAS
  - This is where I am, this is my antenna pattern, this is my TX power, this is my license class, this is my desired channel. Can I transmit?
  - Only applies to basestations
- Low power terminals are not directly managed by SAS
- High power terminals are allowed but must register as CBSD devices
- SAS uses knowledge of devices to determine if the requesting device will cause interference to higher tier users of spectrum
- No protection or coordination is provided among GAA devices
- **SAS is <u>not</u> a realtime scheduler!**

CBRS Channels: 15 x 10MHz



- 7 PAL licenses are available in any one census tract
- PAL license region is the left 100 MHz of the CBRS band (10 channels)
- No single entity can own more than 4 PAL licenses

- Environmental Sensing Capability (ESC) devices will be used to detect navy ships and trigger removal of users currently occupying the band

CBRS Device Details

- Category A CBSD's
  - 30 dBm EIRP (1 Watt) / 10 MHz
  - Fixed location, indoor or outdoor
  - Antenna < 6m if outdoor
- Category B CBSD's
  - 47 dBm EIRP (50 Watts) / 10 MHz
  - Fixed location, outdoor only
  - Professional installation required
  - Antenna < 6m
- CBSD's have a vertical positioning accuracy requirement of +/- 3m
- Terminals
  - 23 dBm EIRP (0.2 Watts) / 10 MHz
  - Mobility allowed

Dynamic Spectrum Management Examples

- Navy ship radar is detected outside of Norfolk, VA on channel #4
  - All devices (PAL or GAA) operating on channel #4 are instructed by the SAS to cease operations
  - Devices are free to contact the SAS for a new channel allocation
- New PAL device wants to start transmitting on channel 2 where GAA devices are currently camped
  - All GAA devices are instructed by SAS to cease operations on channel 2
  - GAA devices are free to contact the SAS for a new channel allocation

Interest outside the US

- UK and EU regulators are observing progress in the CBRS band

Timing in CBRS

- CBRS is a TDD band
- Great interest in deploying LTE in CBRS band
  - “Small Cells”
- Different than previous LTE-TDD bands
  - Different spectrum emissions mask requirements
  - Localized, **possibly non-planned**, deployments

Opportunity for Timing Community

- How can an untrained individual deploy an LTE basestation with proper timing?
- Distributed timing solutions
- Indoor, outdoor, small cell, enterprise, mom & pop
- Residential femtos problematic
  - eLoran a solution?
- Instead of providing one large timing solution to one large entity, there will be many smaller entities looking for solutions specific to their environment

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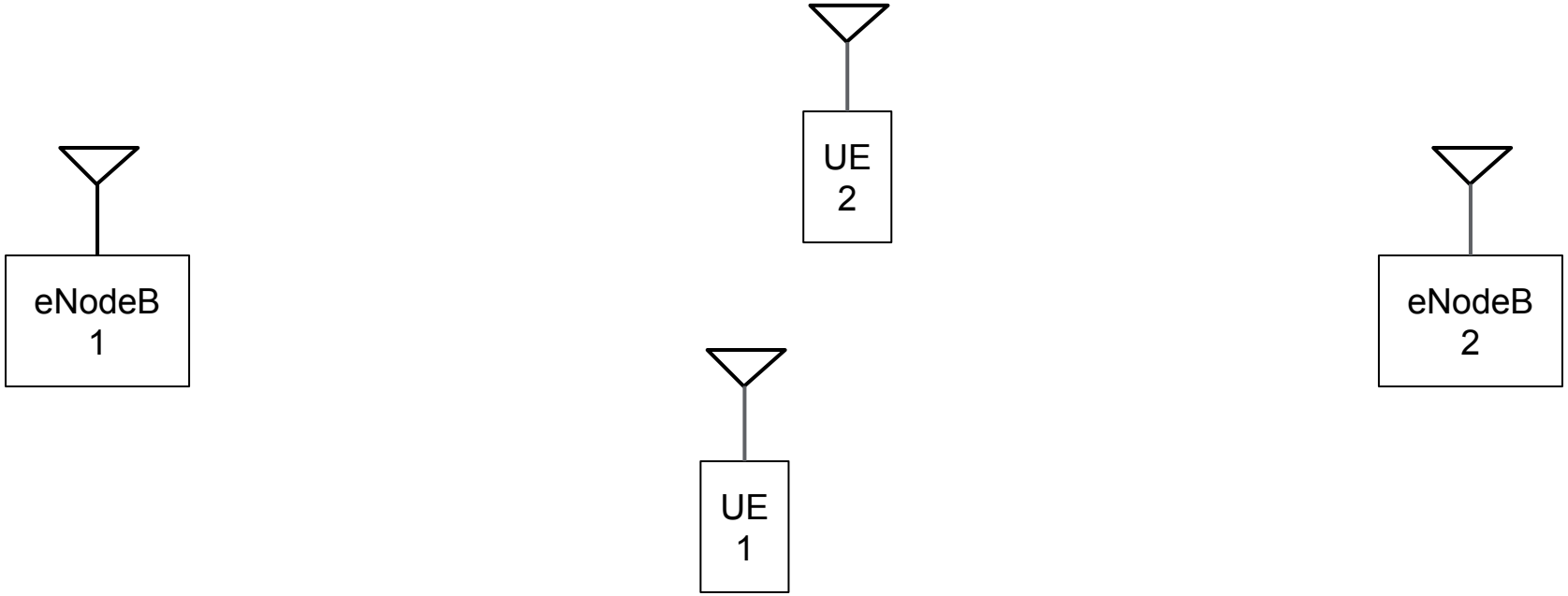
LTE TDD Interference - Co channel



- Problems exist when one device is in RX while a nearby device is in TX

Interference Pairings

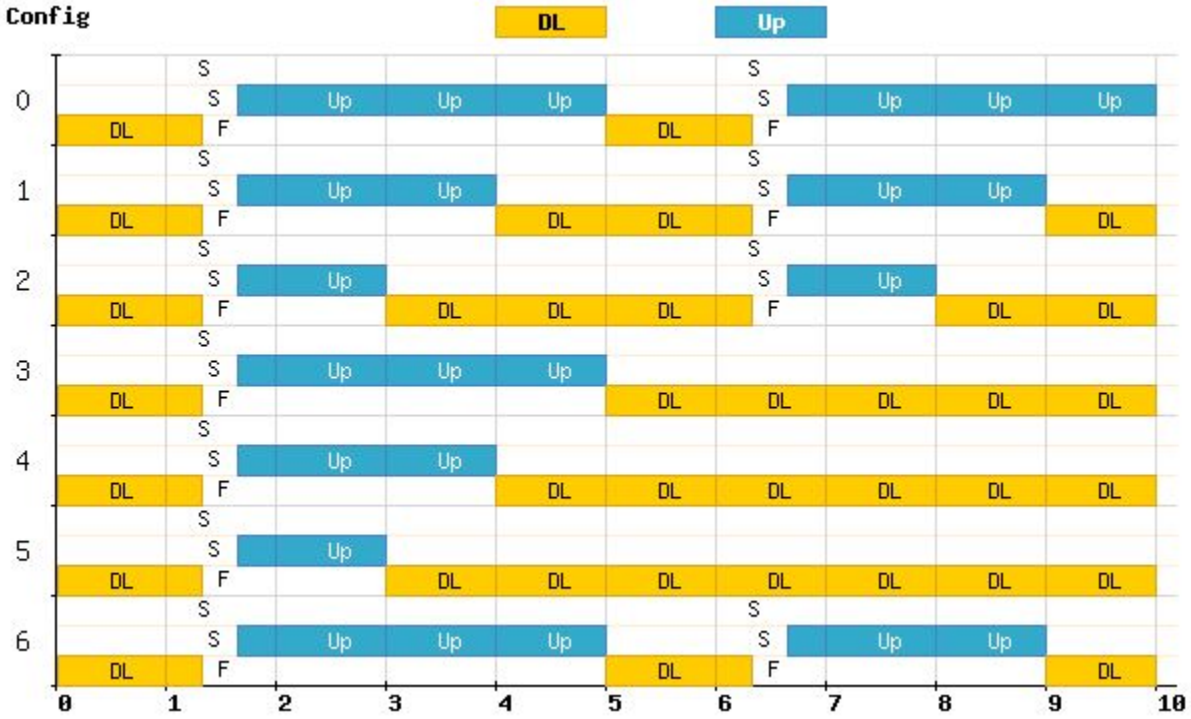
eNB1 ⇔ UE2 eNB2 ⇔ UE1	Normal interference scenario (poor timing can affect interference rejection algorithms)
UE1 ⇔ UE2	Significant interference
eNB1 ⇔ eNB2	Significant interference

LTE UL/ DL timing

Uplink-downlink configuration	Subframe number									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

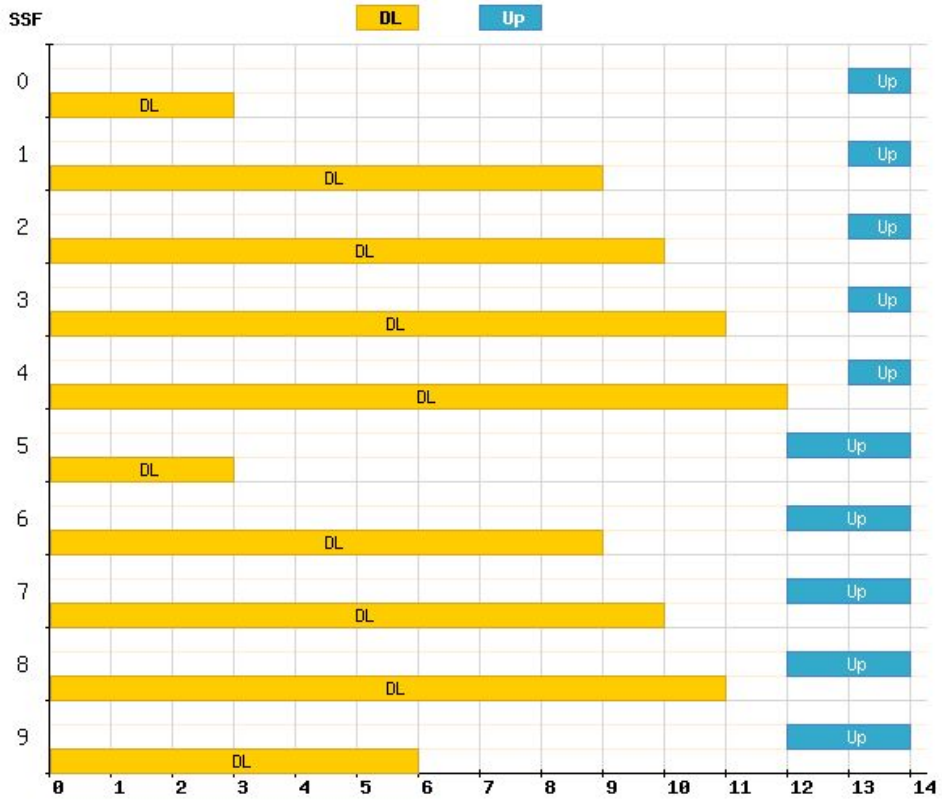
3GPP TS 36.211 Table 4.2-2

LTE UL/DL Timing (More detail)



http://niviuk.free.fr/lte_tdd.php

DL to UL switch point @ eNB



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DL to UL switch point (UE ⇔ UE)

- Beginning of UE1's PRACH transmission should not be earlier than the end of UE2's DL reception.
  - $t_{error} < t_{GP}$-15 μs - $t_{UE,RX->TX}$ - ($t_{prop,enb2-UE2}$-$t_{prop,enb1-UE1}$)
- Not a problem unless UE2 is much farther from eNB2 than UE1 is from eNB1.
- Only happens in a network where eNB's have vastly different TX power levels.
- Can always increase guard period.

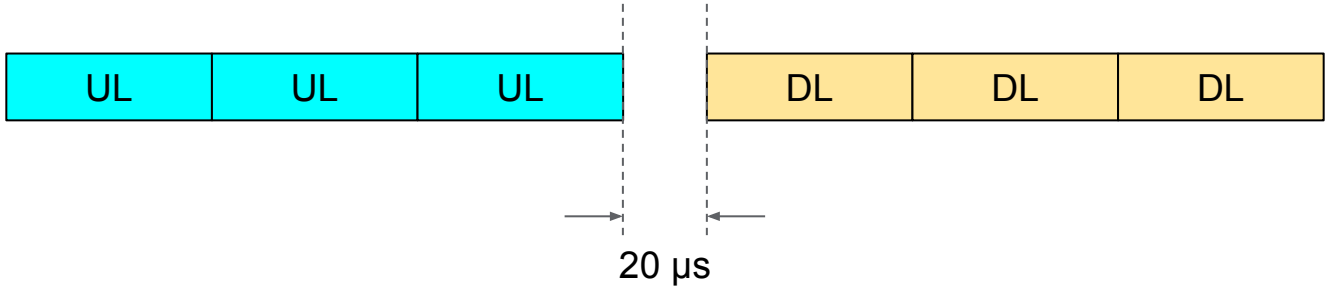
http://www.3gpp.org/ftp/tsg_ran/WG4_Radio/TSGR4_48/Documents/R4-081908.zip

DL to UL switch point (eNB ⇔ eNB)

- If DL from eNB2 is delayed by too much, it can interfere with reception of PRACH by eNB1
  - $t_{error} < t_{GP} - 15\ \mu s - t_{BS,TX->RX} - t_{prop,enb1-enb2}$
- Not a problem unless eNBs are separated by large distances but in that case, signal power is very weak.
- Can always increase guard period.

http://www.3gpp.org/ftp/tsg_ran/WG4_Radio/TSGR4_48/Documents/R4-081908.zip

UL to DL switch point @ eNB



UL to DL switch point (UE ⇔ UE)

- UE1 must stop transmitting before UE2 starts receiving
  - $t_{error} < 20\ \mu s - t_{UE,TX->RX} + t_{prop,enb1-UE1} + t_{prop,enb2-UE2}$
- Theoretically, for UE's very close to their small cell basestations, $t_{error} \sim= 0$
- Depends on $t_{UE,TX->RX}$

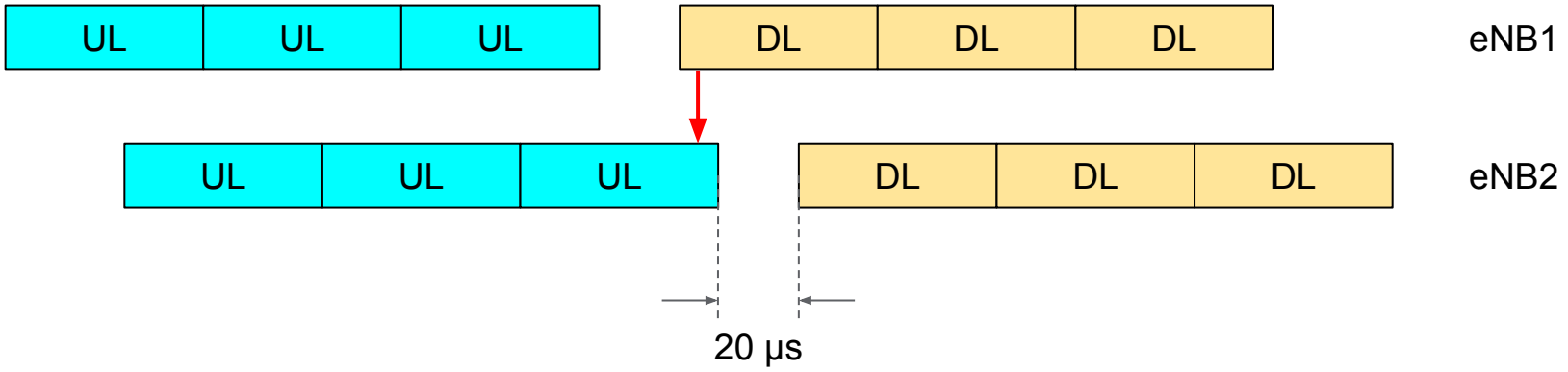
http://www.3gpp.org/ftp/tsg_ran/WG4_Radio/TSGR4_48/Documents/R4-081908.zip

UL to DL switch point (eNB ⇔ eNB)

- eNB2 should not begin transmitting before eNB1 has finished receiving
  - t_{error} < 20 µs - $t_{BS,TX->RX}$
- Depends on $t_{BS,TX->RX}$
  - Spec is 17 µs
  - t_{error} < 3 µs

http://www.3gpp.org/ftp/tsg_ran/WG4_Radio/TSGR4_48/Documents/R4-081908.zip

eNB ⇔ eNB interference

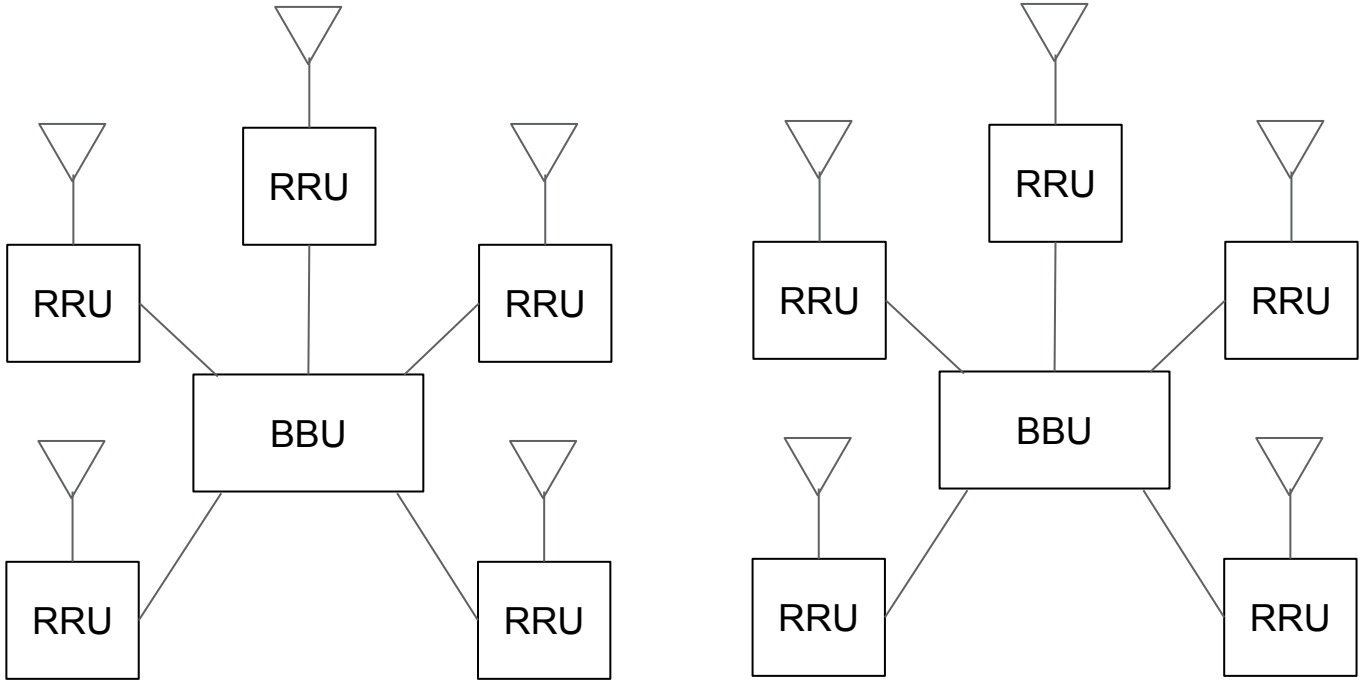


Final timing spec

- Final timing spec was chosen, in 2008, to be 3μs
  - 8 years ago

- Timing is not as much an issue for handover in LTE
  - All handovers are hard handovers requiring initial PRACH transmissions
- It is an issue for WCDMA

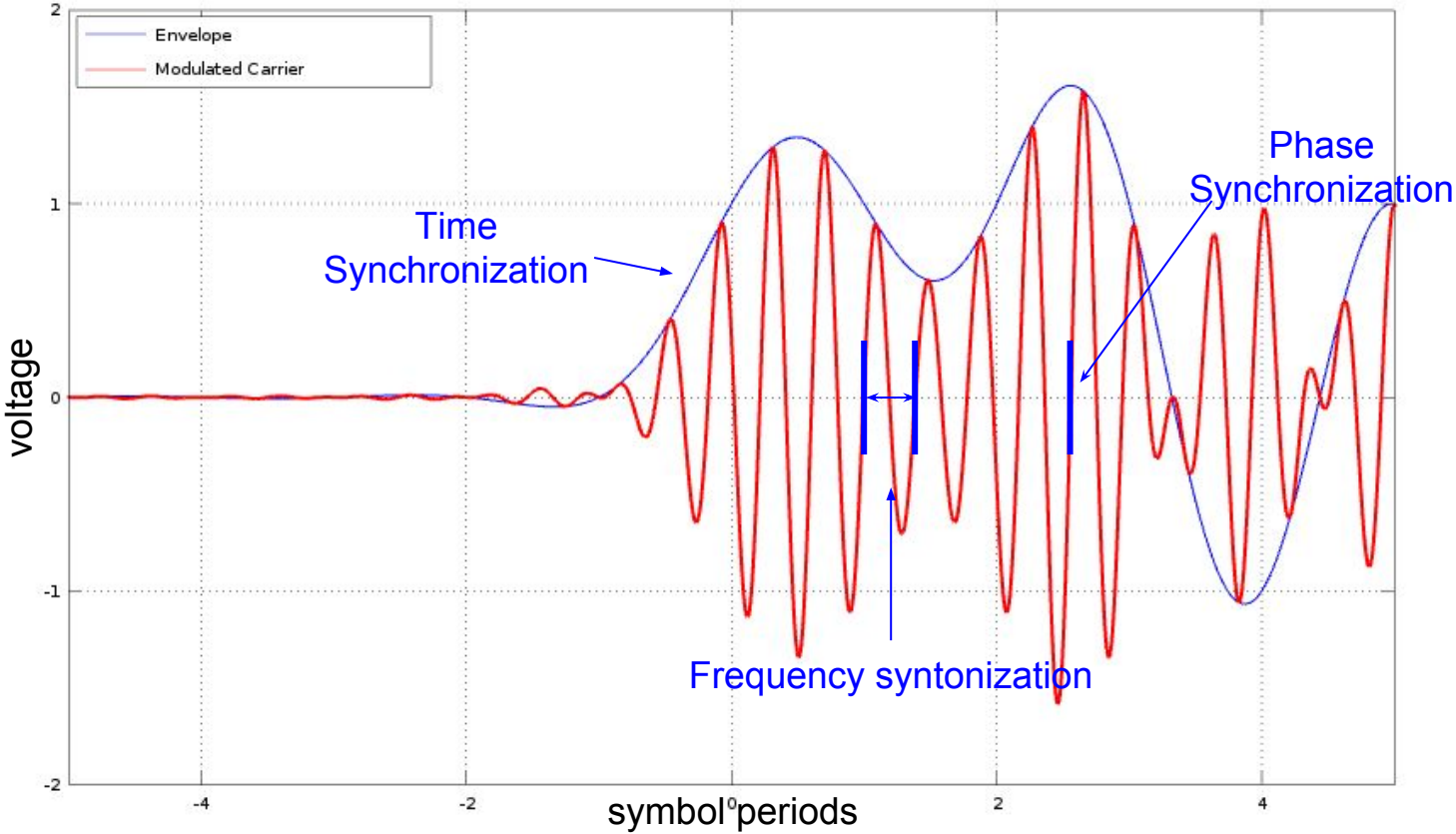
Modern LTE Deployments



Channel Coherence Time @ 3.5 GHz

UE Speed	Channel Coherence Time
0 kph	Infinite*
3 kph	13 ms
10 kph	4 ms
30 kph	1.3 ms
100 kph	0.4 ms

Frequency, Time, and Phase (FrTiPh)



FrTiPh Stability Requirements

Synchronization Domain	Stability Requirements		Geographical area
Frequency Syntonization	Short term and long term	ADEV < 50e-9	1 eNB
Time Synchronization	Short term and long term	TDEV < 1.5 µs	Entire Network
Phase Synchronization	Short term	TDEV(4ms)<10ps	CoMP area

What can I do, in LTE, with 1ns timing at the eNB?

- Better positioning
  - In non-LOS environments, limiting factor is uncertainty of channel delay
- Reduced channel estimation for static UE's
  - If environment is changing, channel estimation still necessary
- Mosquito zapper
  - Concentrate energy from 100 antennas onto a single location

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Thank You to the Timing Community

- The community has been very welcoming of a newbie.
- I’ve had direct access to some of the top minds in the industry.
- There are many brilliant people involved that have made an amazing science out of the study, generation, and distribution of time.

Real world PTP experiences

- G: “Does your switch do PTP?”
- ABC: “Of course! It says so right on the box!”
- G purchases switch and tries to turn on PTP
- ABC: “Oh yeah, about that PTP thing. We actually haven’t written any code for that yet…”

Real world PTP experiences

- XYZ: “Our switch is great! It can do PTP over VLAN’s which our competitors cannot!”
- G purchases switch and tries to turn on PTP over VLAN
- “Oh yeah, about that PTP VLAN thing… It only works in certain network environments. Your environment isn’t one of them.”

Real world experiences

- P298: “We have this great new clock that supports G.8275.1!”
- G: “Great! So you support SyncE?”
- P298: “No”
- G: “Isn’t SyncE required for G.8275.1 support?”
- P298: “...”

Real world experiences

- G: “I see that our BC’s do not perform any filtering of the incoming time estimates. Why not?”
- ZQWP: “In our target industry, our customers requested that we do not perform filtering.”
- G contacts customers in their target industry who state that they never made such a request. They would prefer some sort of a loop filter.

End result

- We regularly spend days (even weeks…) just getting two pieces of equipment to talk to each other.
  - No timing performance measurements made.

- We cobbled together a PTP network.
  - We found a combination of commands/ configurations that make GM A talk to Switch A
  - We found a combination of commands/ configurations that make Switch A talk to Switch B
  - We found a combination of commands/ configurations that make Switch B talk to Small Cell A
  - Repeat for GM B, Switch C, Small Cell B, etc.

Thanks

- I’ve been fortunate to be able to spend time with several experts in the industry. I appreciate their patience with my questions.

- Special thanks to my colleagues at Google that come from the timing community:
  - Sebastien Jobert
  - Tim Pearson