LTE/DO – a handset/component perspective
Outline

• RF options for LTE/CDMA and issues
  ♦ Difficulties with two transmitters

• Network solutions for “1T/1R” radio

• One possible BB/RF construction, and service rollout plan

• Insights into chip construction

• Conclusion
## Handset RF options

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- **CDMA Tx**: Higher mobile BOM, Mobile performance issues, Easier for network
- **CDMA Rx**: Lower mobile BOM, Easier for mobile, More difficult for network
RF component ecosystem issue

• A standard LTE radio can probably do CDMA (*)

• However, it cannot do LTE and CDMA at the same time

• It is certainly possible to implement a radio which will do LTE and CDMA at the same time (either Rx or even Tx/Rx on both systems at the same time).
  • However, this style of LTE/CDMA radio would be burdened with much extra complexity, and therefore would not be competitive in the LTE-only space.
  • It is advantageous to allow usage of a standard RF component with a worldwide ecosystem.

Simultaneous Voice/Data issue

- LTE VoIP + LTE data is ultimate solution.
- But LTE VoIP with circuit-switched quality, capacity, and coverage is many years away for most carriers.
- HSPA+WCDMA can operate on one RF carrier, and thus a natural plan for 3gpp terminals is to fall back from LTE to HSPA/WCDMA when SVD is needed.
- However, CDMA has no such SVD standard
  - EV-DV was that standard, but it died
- Therefore in CDMA, intermediate SVD options are only:
  - LTE+1x → two RF carriers.
  - DO + 1x → two RF carriers.
  - DO VoIP + DO data → same challenges as LTE VoIP
  - 1xSCH + 1xVoice → very low data rates on 1xSCH; also it is effectively circuit switched.
Summary of tradeoffs

• **1Rx/1Tx:**
  - Cannot do any two carriers at the same time (LTE data + 1x voice, or DO data + 1x voice) (*)
    - Some possible workarounds covered in subsequent slides
  - Allows use of standard ecosystem component

• **2Rx/1Tx**
  - Can at least look for pages on unrelated system while full Tx/Rx on the another.
  - Avoids many Tx interference problems.
  - Extra standby power (2 paging channels)
  - Uses a specialized transceiver, or two transceivers.

• **2Rx/2Tx**
  - Simultaneous everything with no network effort
  - Worst performance and complexity
  - Two full transceiver chains

(*) NOTE – option exists to do single wideband RF, but frequency plan extremely limited. Does not work for most real-world situations.
Difficulties with two transmitters
Summary of SVLTE issues

- **IMD & crosstalk**
  - Possible coverage issue (subsequent slides)

- **Isolation**
  - Achieving even 10dB of isolation between antennas in nearby bands requires effort. Each dB thereafter is an increasingly difficult struggle.

- **Antenna volume**

- **SAR at peak conditions**

- **Thermal and battery drain**
  - To some extent an unavoidable problem with many bits/sec, no matter how they are sent.
  - But two separate systems will take more power, and generate more heat
Two possible radio arrangements (1)

- **There are two main options**
  - Both are in production today in the market

- **Option 1: Data vs Voice**
  - Requires some integration between LTE + DO.
  - Supports SVDO naturally
  - Must use measurement gaps for LTE->DO handdown.
  - 1x can slot independently of DO
Two possible radio arrangements (2)

- **Option 2: LTE vs CDMA**
  - Supported by legacy components (less integration required)
  - May or may not support SVDO or SHDR
    - Depends on CDMA RF
  - Can search DO during LTE (not just during gap), therefore LTE to DO handdown is slightly easier.
  - However, conversely, 1x and DO may have some dependency
    - Depends on CDMA RF support for SVDO and SHDR
Many topologies

But within these two options, there are almost infinite variations of topology

- Generally speaking, SVLTE introduces much complexity.
- SVLTE w SVDO introduces still more complexity
- Diversity on LTE is always required, but diversity on DO or 1x in 2Tx case introduces still more complexity.

Subsequent slides show some examples, but are by no means exhaustive – this is a long topic by itself.
With SVLTE but not SVDO

- In this example, non-integrated BB
- CDMA RF: 2Rx/1Tx
- LTE RF: 2Rx/1Tx
- One antenna dedicated to Tx on LTE; the other dedicated to Tx on CDMA
SVLTE and SVDO (w/o DO diversity)

- CDMA RF: 2Rx/2Tx
- LTE RF: 2Rx/1Tx
- One antenna must Tx on both LTE and CDMA
SVLTE&SVDO w DO diversity

- CDMA 1x RF: 3Rx/2Tx
- LTE/DO RF: 2Rx/1Tx
- Two main antennas and one diversity antenna
- Others
  - 2 TCXOs
  - 5 PAs
No simultaneous Tx is much simpler!

- CDMA/LTE RF: 2Rx/1Tx
- One main antenna and one diversity antenna
- Others
  - 1 TCXO
  - 3 PAs
SVLTE Issue (1/4)

Band 13 LTE and BC0 CDMA

- **IM3 due to CDMA Rx LNA and Hexa-plexer**
  - LTE Tx & 1x Tx → 1x Rx

- **IM3 in LTE Rx LNA and Hexa-plexer**
  - LTE Tx & 1x Tx → LTE Rx
SVLTE Issue (2/4)

BC0 CDMA and 2.6GHz LTE

• IM3 due to CDMA Rx LNA and Hexa-plexer
  - LTE Tx & 1x Tx → 1x Rx

• IM3 in LTE Rx LNA and Hexa-plexer
  - LTE Tx & 1x Tx → LTE Rx
• **Assumption**
  - IIP3=8dBm
  - Filter rejection=50dB (LTE)
  - Filter rejection=53dB (CDMA)
  - Insertion loss=3dB
  - Antenna isolation=10dB

• **IM3**
  - $P_{im3} = P_{lte} + 2*P_{cdma} - 2*IIP3 - 3dB = -40dBm + 2*(-26dBm) - 2*8dBm - 3dB = -111dBm$

  (-3dB is because IM3 product has about double BW)
  - Where $P_{lte} = 24dBm$ - (back off) - (antenna isolation) – (filter attenuation) = $24dBm - 4dB - 10 - 50 = -40dBm$ (Plte at the LNA input)
  - Where $P_{cdma} = 24dBm +$ (insertion loss between antenna and PA) – (duplexer isolation) = $24dBm + 3dB - 53dB = -26dBm$
• There is a SPDT or hexa-plexer in front end.
  - SPDT IIP3=65dBm
  - hexa-plexer IP3=80dBm
  - Antenna isolation=10dB

• IM3 due to SPDT: doesn’t work
  - Pim3=(Plte+2*(Pcdma-Giso)-2*IP3-3dB)-Giso
    =(24-4+2*(24-10)-2*65-3)-10 = -95dBm

• IM3 due to hexa-plexer
  - Pim3=(Plte-Giso)+2*Pcdma-2*IP3-3dB
    =(24-4-10)+2*24-2*80-3 = -105dBm
Exponential difficulty

- There are many combinations of situation with two bands.
- There are many more with three bands.
- Each new band presents new issues with regard to each of the other bands.
- Thus the complexity is exponential in the number of bands.
- World-mode handset becomes impossible.
Max-power backoff

• 1x system needs max power for coverage.

• LTE system may reduce its max power when 1x system is at max power,
  - Helps with SAR, and also with coverage issue
  - Handsets in the market appear to use complicated proprietary algorithms, including consideration of which channels are being used.
    • Carrier and standards-bodies specifications are insufficient to address the problem.

• Some devices (both multi-mode and otherwise) are using proximity detection or VSWR detection to reduce max power.
  - There are not detailed specifications around the usage of this technique
  - If applied excessively, it would result in compromised coverage.
Most networks are a mixture of forward and reverse-link limited, depending on a dynamic situation.

Laborious network tuning ensures that network will perform acceptably with while transmitting CDMA max power.
  - Must maintain forward link coverage with a specified desense from max-power Tx on the reverse link.
2-Tx cell shrink (2)

- But adding another transmitter (with associated crosstalk and intermod), there will always be some further desense.
  - May leave mobile without sufficient Rx sensitivity.
Diminishing returns on isolation

- Have been told by many that “spec for LTE desense to voice is ‘none’”. This is not possible.

Reducing interferer from:

- -6dB to -9dB yields about 1/2dB improvement
- -9dB to -12dB yields about 1/4dB improvement
- -12dB to -15dB yields about 1/8dB improvement...
- ...and so on.

X = Noise2/Noise1
(in dB)
Y = (Noise2+Noise1)/Noise1
(also in dB)
Additional power of monitoring another paging channel

• Some have expressed concern about the power monitoring two paging channels

• This is probably less a concern than the BOM and ecosystem issue.
  
  • 1-2mA to monitor paging.
  • Typical smartphone has quite a large battery, e.g. 1500mAh.
  • At one day-of-use, that is 62.5mA
  • Augmenting this by 1-2mA is only about one and a half to three percent increase.
Carrier aggregation

• There is some danger that LTE carrier aggregation could introduce some of the same problems as SVLTE

• This is being discussed in 3gpp now
  - One solution is asymmetry (aggregate Rx, leave 1 Tx)

• Avoiding 2-Tx considerably simplifies the handset
  - It is the same issue, whether those two Tx signals are the same mode or different modes
Network solutions for 1T/1R radio
Summary of options

- S101/S103
- S102
- Standards change to enable monitoring of paging during 4G.
- System-selection only.
• **S102**
  - Enables CSFB & eCSFB

• **S101/103**
  - Enables optimized data handover.

• **Reserving an arbitrary gap**
  - If foreign system can reserve an arbitrary gap in native system, then can monitor paging.
  - Network implementation simple because no need to connect networks.
  - Mobile already knows the timing of both, and can do the management.
  - However, this method is not standardized; some discussion, but little progress.

• **System Selection only**
  - No connection, no interoperation.
  - Backup mode for coverage only.
Many algorithms yet to be implemented

• As no carrier is presently using CSFB, there are many implementation details to work out.
  - Exactly how to use measurement gap
  - How to determine channel assignment in tunneled page.
  - Procedures for finding better CDMA channel once the RF is tuned to CDMA
  - Recovery procedures in case of problems

• There is much debate about the merits and difficulties of eCSFB versus CSFB

• These problems are surmountable, but should receive urgent attention from all vendors
One possible BB / RF architecture, and service rollout plan
In an ideal world you would have...

• Simultaneous voice and data (at least most of the time)

• Coverage (all of the time)

• Components and handsets from worldwide ecosystem
  - No extra complexity
  - Common ecosystem (to the extent possible) even though carriers migrate to 4g at different times.

• Flexible network rollout timing
**Component and handset ecosystem**

- **Goal is that “standard LTE components” can be sold into an LTE/CDMA market.**
  - In other words, the complexity adder for supporting CDMA should be small enough that a LTE/CDMA chip is practical for worldwide use, including in LTE-only markets.
    - Otherwise, the LTE/CDMA carrier would STILL be buying specialty components, which would defeat the purpose of deploying LTE (i.e. worldwide device ecosystem).

- **This should be true at the chip level AND at the handset level**
  - Meaning, if a handset has custom mechanical requirements for CDMA, that will also put the carrier in a poor ecosystem, even if the underlying chips are standard world-ecosystem chips.
Flexible RF configuration

- One way to handle both types is to retain optional legacy CDMA RF interface (*)

(*) could be twin LTE RF component if prices for LTE RF fall to legacy level.
Advantages of this approach

• **Support 1-RF and 2-RF structures with one baseband.**
  - Leverages BB across multiple markets – same for 1RF and 2RF cases.
  - 1-RF and 2-RF Handsets are only slightly different.
    - Much SW and integration work can be re-used.
  - Possibly re-use LTE RF in both LTE and CDMA roles
    - Right now a 4g transceiver is significantly more complex, but that difference could disappear over time.
    - Requires further study.

• **Easy migration for carrier**
  - With low LTE initial coverage, can use 2-RF to provide simultaneous voice and data (SVD)
    - Or simply to receive pages
  - As network evolves, can drop back to 1-RF
    - use LTE VoIP + LTE data for SVD, and CS fallback to complete the coverage (without SVD)
  - 1RF and 2RF variants are similar enough to give some benefits of re-use and scale, even as carriers migrate at different times
• **S102 is key to enabling the 1-RF option.**

• **This can co-exist with LTE VoIP**
  - Carrier can advertise “supporting simultaneous voice and data”, (using LTE VoIP + LTE data).
  - Customer simply experiences suspended data traffic when outside of LTE coverage, but still has full voice connectivity always.
  - Network and service planning become infinitely easier for the carrier.

• **SRVCC would be useful in this scenario, but is harder to implement than CSFB**
  - Carrier can select migration plan based on SRVCC, or not. The important thing is to get to a one-RF structure.
    - CSFB, eCSFB, and/or SRVCC.

• **Also eliminating 2-Tx allows network rollout to avoid 2-Tx “cell shrink”**
This is not some theoretical future RF...

- Component makers (RFIC, PA, duplexors) are already supporting multi-mode
- And RFICs supporting many inputs and outputs for a range of bands
• Just as one example, Fujitsu already offers RFICs that support multi-mode GSM / GPRS / EDGE / CDMA / TD-SCDMA / WCDMA / LTE-TDD / LTE-FDD on a single IC
  - already support LTE, CDMA and WCDMA on same physical port and path
  - Saw-less TX in CDMA, WCDMA, LTE Modes
  - No LNA’s required in any mode
  - Saw-less RX in CDMA, WCDMA, and LTE modes
  - Cover a range of bands from 700-2700MHz

• Duplexer and PA choice is only major consideration
  - Certain LTE PAs support CDMA
  - Certain LTE Duplexers support CDMA

• Future will bring even more innovation from Fujitsu and other RF makers
  - E.g., higher bandwidths, broader range of band support
Example front end (not shown: optional diversity Rx path)

- Primary & Diversity Rx for all Bands with 3 Duplexers, 3 PAs and Antenna switch
- More Ports available for TX, RX and Diversity Rx for additional Bands
The mode-agnostic handset

• Note: this RF is using the same path regardless of mode.

• There is a cost (PA, duplexor, etc.) to access a band

• BUT – this cost is the same no matter what mode you use in this band.

• The bands you need to use are determined by what licenses you bought from your regulating government agency; a device vendor can’t help you change that.

• But once you have a set of bands, it IS feasible to make mode deployment completely flexible.
The mode-agnostic handset (2)

• Note that this brings benefits of scale, even if you never use one of these modes.

• Tier-1 maker can make one handset for all carriers. There is approximately no cost for the “unused” modes.

• Handsets for various carriers can literally differ only by SW (or by PRL)

• Note that with 1 band operating at a time, the complexity is linear vs the number of bands, not exponential as in the two-Tx case.
Insights into chip construction
Cost down over time, even in same technology

- A 2G function, same technology node (including optical shrinks), over 9 years

- Primarily a combination of wafer price and enhanced design
Transistors reduce faster than assembly and test

Die
Test
Assembly
Packaging issue

• Packaging cost is actually going up, not down

• Shrinking process technology is good for die size, but puts the I/O’s in a smaller space.
  • And complex systems have more I/Os also

• More I/Os in smaller space leads to routing congestion on the substrate, and increased package complexity

• Progress on this issue has not kept pace with increased die density.
Transistors become free over time, However...

- Early 4G modems in the market are quite large.
- This is probably a mixture of early implementation and inherent complexity

Based on publicly known die sizes and wafer costs, we are similar to this level. It is like 2G 10 years ago.

- Not clear how quickly this will reduce.
Also, AP+LTE may be in poor yield region

- Based on measurements of current AP and 3G/4G modem sizes, all-mode modem plus AP is in a poor yield region, even in advanced process.
- Needs leading edge process (or beyond)
However, die size added for additional 3g or 2g mode is quite small.

- Examine typical LTE modem based on teardown of recent products.
- Examine RTL and memory specific to EVDO
  - Assuming shared ARM, shared peripherals.
- Conclude: a 4g modem SOC might only be increased by 2% by the addition of EVDO.
- With SDR implementation, it could be 0%
Sidebar on SDR

• SDR can work – it is in the market now.

• However, when porting legacy modes, the same facts that make SDR practical (i.e., reduced transistor size and power) also make the cost of retaining a separate legacy hard block very small.
  - Thus there is a tradeoff NRE to port, versus a small cost adder of retaining the original design.
  - And that cost will shrink in absolute terms over time anyway.

• Conclusion is – both way can work.
  - Over time, the difference between the two approaches reduces.
  - (i.e. the legacy block cost reduces both in absolute terms, and also as a percent of the total system)
Silicon conclusion

• Given a constant feature set, the die complexity will reduce both in absolute terms and also as a percentage of the overall system.
• 4G + leading edge AP is quite complex today.
• However it will probably reduce over time, based on history.
• In any case, legacy modes are small compared to the 4G+AP system.
  ♦ Thus it makes sense to implement legacy modes with 4G BB.
  ♦ i.e., there is no point to have a separate 4G design based on the presence/absence of one 3G/2G mode.

• Corollary point – there is still a big delta in complexity today between 4G and 2G/3G. We have a some distance to go before 4G could reach 2G/3G costs.
Trends driving “all mode”

• **Chip-level Trends:**
  - transistors cost less,
  - package costs more (more bonds, and smaller)
  - NRE much higher
    - Mask ; layout; IP verification
  - Integration risk higher; timing, DFT, yield, voltage management all much more complex

• **Phone level trends:**
  - Component costs lower
  - Modem smaller fraction of component costs
  - NRE costs higher
    - SW development
    - HW and mechanical development
    - Integration and validation of increasingly complex systems.
  - IPR cost flat – agreements tend to include everything

• **Tier-1’s looking to do one iconic design and sell it worldwide**
• **They do NOT want to do a specific mechanical / antenna design for CDMA-based mobiles.**
Overall Conclusion

• **Some type of single-transceiver method is important to reducing handset complexity**

• **With 1-RF, the additional complexity of carrying CDMA can be approximately zero.**
  - This is true for BB, RF, and overall handset.
  - This also allows CDMA carrier to be in a “worldwide ecosystem” of not only components, but also handsets.
  - There is a cost to access spectrum, but that exists no matter what mode you run in your spectrum.

• **With 2-RF, the additional complexity of carrying CDMA is significant.**
  - Handsets are also dedicated-design, leading to poorer selection for the carrier.