RTT	**RTT TECHNOLOGY TOPIC December 2011**
	Making Smart Phones Work (3)

This is the third of a series of Technology Topics in which we review the technical and commercial dynamics of the smart phone supply chain including semiconductor and RF component vendors, device vendors, infrastructure vendors, operators and end users.

This month we look at the LTE uplink and how a different approach to admission control and power control combined with a different approach to power amplifier design improves the economic efficiency of LTE networks irrespective of the band into which they are deployed.

The RF performance of user equipment has always had a dominant but often underappreciated impact on RF network economics. The transition to mobile broadband makes the RF performance of user equipment more rather than less important. This is particularly true for smart phones but applies to dongles as well.

Our thanks to the operators and vendors who have taken time to review this topic prior to general distribution. This is a complex subject and some assumptions and conclusions remain open to debate. **Comments** as always are welcome.

Power control - past, present and future

All cellular systems to date have implemented power control, the process by which the base station measures the signal strength and signal quality on the uplink and downlink and then sends power up or power down instructions to the mobile to compensate for path loss and channel fading.

The same process is used to manage handover decisions with interference as an added input to the decision process.

The transition to 3G systems made some things easier and some things harder. Channel spacing increased from the 25 or 30 KHz used in first generation systems to the 200 KHz used in GSM to either 1.25 MHz (CDMA) or 5 MHz (Release 99 UMTS).

This made frequency planning easier at network level and to an extent relaxed the synthesiser performance and frequency reference requirements in user and base station equipment at least in terms of resolution though noise specifications became more stringent. Additionally channel to channel selectivity and user to user selectivity had to be achieved using Walsh codes (CDMA) or OVSF codes (UMTS).

These provide an effective code domain mechanism for de correlating wanted signal energy from a noise like channel but the effectiveness of the process is dependent on closely managed power control to ensure that multiple users are received by the base station at similar symbol level power, ideally within 1 dB of each other.

For an acceptable coverage area this requires the mobile device to control its power over a 78 dB power range, nearly 100,000,000 to 1. By contrast, GSM/GPRS/EDGE devices have 40 dB of mobile transmitter power control, less than 10,000 to 1. The power control loop is therefore more complex than prior systems and depending on the level of mobility in the user group the associated signalling absorbs additional power and bandwidth.

This power control is there for a reason and works well in many present applications. It means that for much of the time user equipment is running at a fraction of its maximum output power, typically a few milliwatts or a few tens of milliwatts rather than the 125 or 250 milliwatts potentially available.

However user equipment RF power amplifiers are not inherently efficient when run under these lightly loaded conditions and have to be built with switchable gain stages. These add cost and complexity.

At cell edge, user equipment may need to be backed off in terms of output power to minimise cell to cell interference. This power may be necessary to maintain the call during handover to the next serving cell, avoiding a dropped call.

Even with uplink interference mitigation, the effect of this is that user equipment can be uplink limited more often than it needs to be. This translates into either a loss of range and data rate at cell edge, dropped sessions and or a loss of uplink capacity.

Close in to the cell, uplink offered traffic is limited by the noise rise of the base station receiver front end. The noise rise will initially shrink the size of the cell and ultimately approach 'pole capacity', the point at which user devices are instructed to increase their output power to overcome the noise rise at the base station. This then increases the noise rise.

As operators transition to mobile broadband data dominant networks these edge of cell and close to cell performance issues become more significant as the offered traffic - and by implication the offered traffic power requirements - vary substantially and rapidly both on a per user and multi user basis.

The overall aim is to achieve a sweet spot compromise between delivering data reach and data capacity irrespective of the cell geometry (The distribution of users within the cell). This means giving people acceptable data rates and data capacity at the edge and close in to the serving cell.

The dynamic range of the composite techniques used have to accommodate a wide range of operational conditions from dense urban to deep rural with users who are either standing still, walking or travelling at speed from cell to cell. These are wide area high mobility networks not Wi-Fi networks.

Admission control and power control integration

This brings us to the coupled topic of admission control.

Network efficiency in all data networks, ADSL being one example, is achieved by realising multiplexing gain between users whose bandwidth requirements are continuously changing. This is different from circuit switching when a 'circuit' is dedicated to one user for a specific voice or data or now voice and data session.

In a mobile broadband wide area network, admission control is more complex with a trade-off between user experience and network efficiency. User experience opinion scoring for edge of cell users will be improved when Round Robin scheduling is used. Round Robin scheduling allocates bandwidth to users irrespective of their channel condition at any moment in time. This means that users at the edge of the cell will get either the same amount of bandwidth allocated to them as close in users or potentially additional bandwidth to compensate for the weaker link budget.

The alternative approach is to implement CQI (channel quality indicator) based scheduling where users with the best instantaneous uplink and downlink channel quality will be given preferential access to radio channel bandwidth. Actually it is a bit more complicated than that. CQI can be used to take advantage of short term channel conditions (less than 100 milliseconds) and combined with fair throughput scheduling (on a time base of more than 100 milliseconds). CQI is also used in the frequency domain in LTE.

If CQI is used as the only admission criteria it will yield the highest data capacity per Hz of allocated bandwidth but edge of cell users will rarely get served. All schedulers therefore choose some intermediate position between the two extremes. This is known as proportional fair scheduling or fair throughput scheduling. (As above).

Efficiency gain opportunities

We have said that HSPA devices may have to be power limited at the edge of cell to mitigate cell to cell interference given that most networks are implemented on a frequency reuse of one (the same channel allocated at all sites).

LTE (strictly speaking LTE Advanced) introduces Inter Cell Interference Coordination (ICIC). This manages inter cell interference by ensuring that the user devices that are detected as being potential interferers do not use the same frequency sub carriers as users in the adjacent cell. Similarly problems with insufficient guard band in the frequency domain can be accommodated by not using frequency sub carriers towards the edge of a 5, 10 or 20 MHz channel. If ICIC is not used then the frequency domain scheduler using CQI will do the job adequately and other mechanisms such as the use of the Physical Cell Identifier help as well at least within two or three sector deployments.

On the basis of using any or all of these intra cell and inter cell interference mitigation techniques LTE devices can operate at the edge of the cell at full power. This increases data reach – the distance from the base station where acceptable data rates are still available.

Close in to the cell, user devices can be ‘seen’ by the LTE base station at relatively different power levels, of the order of 20 dB or so. This is because selectivity is achieved in the base station in both the time and frequency domain. This means that the user devices can be operated at maximum power with the power matched to the traffic requirement in both the frequency and time domain.

This makes CQI scheduling more efficient close in to the cell which means that more bandwidth can be made available to those pesky users at the cell edge. This increases data capacity **and** data reach.

But actually it’s better than that. The LTE admission control algorithm works on a time domain resolution of anything between 10 milliseconds and half a millisecond coupled with a decision as to how many frequency sub carriers are made available (the composite term for both of these together being physical resource blocks).

Admission decisions can be taken on the basis of multiple inputs (potentially 32 variables at the last count) but can also be beguilingly simple. As an example, for best effort data the decision can be based on the buffer occupancy of the user’s device. If the buffer starts to get full the device sends ‘sad’ bits to the network. If the buffer is relatively empty the buffer sends ‘happy’ bits to the network. The network then decides on an optimum physical resource block allocation for that single user taking into account the requirements of all other users in the cell and proximate cells.

This means that the allocation of channel bandwidth and by implication channel power can be done in the frequency and time domain. There is no need to power control the user’s device which in turn means that the channel signal energy previously absorbed by power control in the user’s device is now available for user traffic (with associated user value) rather than signalling overhead. There are techniques in Release 7 onwards to reduce this overhead but not to eliminate it altogether.

Assuming the mobiles can run at full power, the only constraint then becomes the dynamic range and selectivity available at the base station, the ability of the base station to handle the offered traffic power. Superficially this seems odd. The base station might be transmitting 20 watts and the user devices are transmitting at most 250 milliwatts but then there could be hundreds of mobile devices firing in to the base station RF receiver front end.

Base stations with more dynamic range and selectivity on the receive path will therefore deliver a significant system efficiency gain. The difference in performance is determined by the architecture used. A low cost base station for example might attempt to down convert a whole band which would mean as much as 70 MHz at Band 7 using one DSP (state of the art is 60 MHz). This will be a low cost approach but will leave the RF front end and baseband DSP vulnerable to overload and non-linear behaviour.

Note that the constraints of a DSP are similar to RF component constraints. The ability of the DSP to handle dynamic range is a function of bit width. The ability to handle high frequency signals across a given bandwidth is a function of bit width and clock cycle count. This is the same cause and effect but described in a different way.

Caveats

There are caveats that need to be expressed.

Fixed power control overheads
The reference symbols in LTE are fixed elements and regular (four per physical resource block) both on the uplink and downlink with the uplink channel quality being reported to the e NB through the CQI symbols. This fixed part of the overhead is therefore inescapable so you may as well get some benefit from it. In most cases LTE will be deployed with other legacy systems so power control may be needed to manage inter system interference both within the user device and within the network. While this is true it is also true that if the signalling associated with the LTE power control loop can be minimised at the physical layer then a link budget gain will be achieved.

User equipment sensitivity
There is no point in increasing the power output of a user's device if the sensitivity is compromised. This means that the isolation in the switch and filter paths needs to be carefully managed in both FDD and TDD systems. TDD systems are not immune to these effects.

ACLR and EVM performance in re farmed spectrum
There is no point in increasing power output in a user's device if this causes problems in re farmed spectrum. This will require 5, 10, 15 or 20 MHz and potentially 100 MHz channels to be deployed in spectral and geographic proximity to 200 KHz GSM or EDGE channel bandwidth. This implies a need to optimise ACLR and EVM performance.

Note that the term re farmed spectrum can also be regarded as applying to new bands such as the 700 and 800 and 2600 MHz bands. Re farming is simply another way of describing the repurposing of existing spectrum. The 1800 MHz for example is arguably a major LTE opportunity in Europe and ACLR performance within this band will be particularly critical.

Heat gain
There is no point in increasing power output in a user's device if the heat rise in the device becomes unacceptable or if the duty cycle is reduced.

Heat rise is important not only from a user's perspective (hot dongle syndrome) but also in terms of what it does to the frequency conscious components in the front end of the phone. Components such as SAW and FBAR filters and resonators and oscillators and MEMS switches may be mechanically compromised by aggressive heat cycling and will certainly be subject to problematic frequency drift.

Impact of the caveats on RF power amplifier (PA) specification
The impact of all the above is reasonably profound. RF power amplifier manufacturers have become used to their customers asking for good efficiency at low output power and or across a wide range of output powers.

Even if low power operation is not used in LTE, the LTE signal itself is a challenge to RF power amplifier designers. The selected signal has a peak power that exceeds the average (information-useful) power by 12 times. For the same average transmitter power – read as the same communication range – the LTE power amplifier must handle this peak power cleanly. For 23 dBm (200 mW) average power the PA must be designed to support 34 dBm (2.4W). Alternatively a smaller and lower cost power amplifier can be used, but the average output power must decrease – reducing the communication range. This is the reason for MPR provisions in the LTE (and HSPA) specifications. Furthermore, the complex LTE signal is not as tolerant of signal distortion as the UMTS/HSPA signals, requiring the EVM spec to be tighter (raising costs).

The impact of RF PA specification on user devices, the perversity of maximum power reduction (MPR) and the impact of user equipment transmit efficiency on network efficiency.

On balance and taking the above caveats into account it can be generally stated that inter system and inter and intra cell interference can and should be managed at system level to allow LTE user devices to be run at or close to their maximum power level.

This is because mobile networks and in particular mobile broadband networks are power limited

not bandwidth limited.

This begs the question as to whether operators should bid for new spectrum or concentrate on achieving better efficiency from existing owned bandwidth. Much of the new spectrum being brought to auction is not as useful as legacy spectrum. It is overpriced and expensive in terms of required capital and operational expenditure and often comes with co-existence issues that need to be resolved. By definition **new spectrum starts with zero scale** which is an additional problem.

Improving the efficiency of existing spectrum will therefore almost certainly result in a better ROI and EBITDA assuming the alternative is adding new bandwidth to an existing legacy band plan.

On this basis the downlink and uplink performance of the UE makes a huge impact on the economic viability of the delivery network. Relaxing TIS and TRP specs to accommodate new bands thereby reducing performance in existing bands is therefore a bad idea.

If we take 'standard 'devices by which we mean devices that support five or at most six bands, handset vendors are now suggesting that RF power amplifiers will be optimised to work somewhere between 19 and 23 dBm. Even this is a big spread with significant fiscal consequences for the operator community. A 3dB back off in user equipment peak power output results in an increase of 45% in the number of base stations required to cover a given geographical area with a given service level. Expressed in terms of constant base station numbers this equates to a 32% reduction in coverage area.

Standards bodies are suggesting that maximum power reduction (MPR) should be considered where linearity requirements and or ACLR or EVM targets are hard to achieve. MPR is where a reduction of the UE maximum output power in the conformance specification is agreed. Additional MPR (A-MPR) allows for adaptive relaxation in certain operational conditions signalled by the network. As a consequence, user equipment designed to an MPR specification can be potentially 2.5 dB down on its originally specified output power and may be coupling with an antenna with a gain of the order of -7 or -8 dB.

This performance spread has to be considered not in terms of user experience expectations as they are today but in terms of user expectations in the future and the network and service value realisable from meeting those expectations.

The LTE peak uplink data rate of 50 Mbps is specified to be an order of magnitude greater than the 5 Mbps promised by HSUPA. Expectations of available rates at cell edge may also be higher than presently assumed and may have a disproportionate impact on the quality of the user experience, both actual and perceived.

This is of course not dissociated with the concept that user value may be more uplink biased than presently assumed, that markets are cost sensitive both in terms of user equipment costs **and** network costs and that many markets combine extreme urban density with wide open deep rural spaces both of which may be subject to different but related uplink power constraints, for example building penetration in dense urban environments and range in rural applications.

One way of solving the coverage issue is to increase network density. One way of solving capacity issues which increase as coverage increases is to bid for more spectrum. Both increase capital and operational costs. These costs are directly a function of the RF link budget closely coupled as stated earlier with multiplexing and admission control techniques. Getting more performance from existing spectrum and existing networks improves ROI and EBITDA. Buying more spectrum and or increasing network density reduces ROI and EBITDA.

In terms of the impact of user equipment performance on network efficiency the focus has generally been on receiver performance, determined by the selectivity, sensitivity and dynamic range of the device. RF transmitter performance is however at least as important. Every dB lost on the transmit path translates into reduced data reach, reduced data capacity and lower user experience scores which in turn translate into revenue loss, churn and or higher retention budgets.

The need to combine an ability to transmit at maximum power while maintaining ACLR and EVM performance is critical particularly when implementing LTE networks into re farmed spectrum.

This power needs to be generated efficiently to maximise user data duty cycle and minimise heat gain within the user's device.

But have I just moved the problem somewhere else?

Well possibly. One consequence of reducing power control related signalling load on the wide area radio interface is that the e Node B base stations will need to do more interference coordination and as a result the backhaul signalling load may increase though if the scheduler is allowed to do the heavy lifting this should not be a major problem.

An additional counter argument is that a 3 or 4 dB gain in the link budget, irrespective of whether it is realised on the wide area access transmit or receive path will reduce the number of point to point backhaul links though not of course the bandwidth needed.

Intuitively given that reducing signalling load on the radio interface increases the ratio of income generating bits to overhead bits (what our Wi Fi colleagues call 'good put') then my hunch is that this is probably where a net gain will be achieved.

Summary – envelope tracking as an increasingly important technique?

The shift in approach towards time domain based admission control in LTE has the benefit that at least some of the power and channel bandwidth previously absorbed in aggressive power control mechanisms is made available as revenue generating bandwidth. This has a similar effect to releasing guard band but is easier to achieve.

Additionally close in scheduler efficiency improves which in turn increases the data reach and data rates available to both close in users and distant users out at the edge of the cell. The gain in efficiency is therefore delivered irrespective of cell geometry.

Running the LTE power amplifiers in user devices at their maximum power means the devices will run more efficiently. This will have a benefit in terms of user data duty cycle which should translate into additional operator revenue. Design goals are however different from those used for developing UMTS power amplifiers and power output has to be achieved without compromising ACLR or EVM performance. This is particularly important when deploying LTE into re farmed spectrum.

Possibly this can be achieved with careful conventional PA design but there is a body of evidence emerging that envelope tracking will be an increasingly important technique that will need to be applied to meet these performance requirements.

Envelope tracking can be achieved either using feed forward or feedback techniques that measure the signal envelope at baseband and compare that signal with the output from the PA and either pre distort the signal or change the operating point of the amplifier.

A detailed discussion of the relative merits of the different implementation options is outside the scope of this technology topic. The success of such techniques is also dependent on achieving a measure of interface standardisation. MIPI http://www.mipi.org/ have just formed a new working group to provide the high speed analogue interface necessary to support ET in a handset.

A parallel benefit of any implementation is likely to be that it will be easier to realise additional functionality such as channel bonding and carrier aggregation and simultaneous voice and data. Multi band implementation should be slightly easier as well.

It is obvious at least to this observer that the arguments being put forward to accept lower output powers (max power relaxation and adaptive max power relaxation) are not consistent with the present and future need to improve user equipment RF efficiency which in turn translates into RF system efficiency which in turn translates directly into network economic efficiency.

The uplink is at least as important as the downlink and arguably becoming more important over time from a user experience (and hence operator value) perspective. It may be particularly important for the **BRIC** markets (**B**razil, **R**ussia, **I**ndia, **C**hina) and the **CIVETS** markets (**C**olumbia, **I**ndonesia, **V**ietnam, **E**gypt,

Turkey, **S**outh Africa) where significant future revenue growth is likely to be realised but where rural data reach and urban building penetration are key requirements.

In previous work we have pointed out that the cost of accepting compromised receive sensitivity in user equipment is disproportionate.

The same arguments apply to transmit power. For any market and any phone design avoid buying into the MPR argument – it will prove expensive in the longer term.

In practical terms small form factor devices, LTE dongles being one example, if operated at maximum power are likely to hit heat rise limits within a few minutes of operation. This has to be resolved. Carrier aggregation makes this worse.

Once again spectral policy and standards policy and to an extent industrial policy have become misaligned with technical reality. Clearly something needs to be done to address this.

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