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Wireless data in a jam?

In this month's Technology Topic we study some of the coverage and capacity issues that are likely to emerge as data rates increase over time.

The issue is not just data rates per se but the growing gap between peak and average data rates. This gap is increasing over time and has implications for radio hardware and backhaul provisioning.

Either additional delivery bandwidth has to be provisioned and/or additional buffer bandwidth has to be supported in the end to end channel.

Present constraints on capital expenditure suggest it will be problematic to provision this additional bandwidth at a sufficiently rapid rate to meet user expectations.

High data rate terminals are part of the problem and theoretically part of the solution. The logic is that if a terminal can send and receive data faster then it will consume less time space in the network.

We use a motoring analogy to show why this is a misconception by posing a simple question.

Will you get to work faster in a Beetle or a Bugatti and what sort of road system will be needed assuming we all have Beetles or all have Bugattis or a mix of the two?

The topic draws on research contained in a thought provoking **study** produced by Moray Rumney, Lead Technologist for Agilent Technologies.

Beetles and Bugattis - a motoring metaphor

In 1937 the Bugatti motor company won the 24 Hour motor race in Le Mans.

70 years later, a renascent Bugatti motor company now owned by VW, is producing a new car, the Veyron, based around a 1000 hp engine. The car is capable of 0 to 60 in 2.5 seconds, 60 to 0 in around the same time and a top speed of 250 miles per hour. At top speed it empties its large fuel tank in less than 12 minutes.

The point of this brief excursion into super car history past and present is that it provides us with an analogy as to why peak data rates in cellular networks are less useful than might be assumed.

The apparent increase in Data Rates over time

In 1987 the data rates achievable in a 25 or 30 KHz analogue cellular radio channel were of the order of less than 10 kbps.

In 2007 WiFi access points offer data rates of greater than 100 Mbps in a 40 MHz channel (two bonded 20 MHz channels).

In parallel WiMax and LTE or UMB systems are promising similar data rates in wide area applications.

In the longer term IMT Advanced networks are being proposed which use a 100 MHz channel to deliver peak data rates of up to 1000 Mbps.

Differentiating peak data rates from average data rates

However WiFi, WiMax and LTE and IMT Advanced data rates are peak data rates sustainable for only short periods of time and supportable only when close to the serving base station.

Additionally the bandwidth is multiplexed between multiple users who either have equal or differentiated access rights.

Thus the peak data rate is divided down as a consequence of the radio limitations of the user device and propagation limits of the radio channel.

The peak data rate may be additionally divided down by the buffer limitations of the user device.

The peak data rate is divided down again by the contention algorithms needed to support multiple users on a common radio channel.

The peak data rate is divided down again if multiple traffic types per user have to supported, for example a multiplex of best effort, streamed, interactive and conversational traffic.

Thus the final average throughput rates are a small fraction of the peak data rates, often of the order of less than 10% and sometimes much lower.

Coverage and capacity trade offs

Additionally we need to consider radio and network coverage and capacity constraints.

Most second generation cellular radio networks have been optimised to provide voice service to the edge of the cell. This implies a cell edge data throughput rate of 10 kbps or so, very similar to the 1987 data rate.

3G networks provide higher data rates at the cell edge by allocating a disproportionate amount of bandwidth and code domain power to a single user for a short period of time.

Base stations particularly base stations implemented on a single 5 MHz channel pair become code bandwidth limited on the downlink.

Users at the cell edge transmitting at maximum power cause maximum interference into adjacent cells which become noise limited on the uplink.

Scheduling as a solution
This problem is resolved or rather minimised by the use of scheduling.

Scheduling comes in various shapes and sizes.

If users are close to the base station it is possible to schedule data bursts at the top of a channel fade.

This is the basis for the 2 millisecond and 0.5 millisecond frame structure in Release 7 HSPA and LTE systems.

As users move away from the base station any theoretical benefit from short term fade scheduling disappears due to signalling load and round trip signalling delay.

Users can also be scheduled on the basis of their overall signal strength which means that users close to a base station or users with good line of site visibility to a base station get preferential treatment.

This works for best effort data but does not help if user sessions are latency sensitive. An over simple implementation of this scheduling algorithm would ensure edge of cell users never received any data which would defeat the object of the exercise.

The impact of high data rate terminals
Returning to our Beetle and Bugatti analogy, Tables 1 and 2 below list present HSPA terminal categories.

Table 1 HSPA terminal categories

Category	Max number of parallel codes	Minimum TTI interval	Transport channel bits per TTI	ARQ type at maximum data rate	Achievable peak data rate (Mbps)
1	5	3	7298	Soft	1.2
2	5	3	7298	IR	1.2
3	5	2	7298	Soft	1.8
4	5	2	7298	IR	1.8
5	5	1	7298	Soft	3.6
6	5	1	7298	IR	3.6
7	10	1	14411	Soft	7.2
8	10	1	14441	IR	7.2
9	15	1	20251	Soft	10.2
10	15	1	27952	IR	14.4

11QPSK	15	2	3630	Soft	0.9
12QPSK	5	1	3630	Soft	1.8

Table 2 HSUPA Handset send data rates

Coding rate	User data rate with one code	User data rate with two codes	User data rate with four codes	User data rate with 6 codes
2/3	640 kbps	1.28 Mbps	2.56 Mbps	3.84 Mbps
3/4	720 kbps	1.44 Mbps	2.58 Mbps	4.32 Mbps
4/4	960 kbps	1.92 Mbps	3.84 Mbps	5.76 Mbps

The number of codes used represents the code bandwidth absorbed by the device, the minimum TTI interval is the resting time needed by the device to process a data burst. The number of bits per transmission time interval is a consequence of the code bandwidth and modulation used. Incremental redundancy provides some additional throughput but adds memory cost.

There are **devices sampling today** that are Category 9 10.2 Mbps on the downlink and 5.7 Mbps HSUPA on the uplink.

The Bugatti would be the Category 10 version.

The theory is that because this device can receive and send data faster than other devices it will occupy less time space in the network.

However during the time the device is active it is taking up proportionally more code bandwidth than other devices.

The cost of the performance gain is therefore paid for by other users.

The gain is also consequent on having appropriate network conditions.

The M25 Wireless Data Jam
For those of us with the misfortune to use the M25 motorway around London, also known as the world's largest car park, the analogy is clear.

The Bugatti can go faster than other cars. It can also accelerate and decelerate faster than other cars.

It can therefore be more opportunistic than other cars when a gap in the traffic appears.

On the M25 in rush hour, which we will call 'Busy Hour,' it would suggest there should be a minimum speed limit. If this was for example 140 miles per hour rather than 70 miles an hour the motorway could support twice as many cars provided of course they were all Bugattis.

However most studies suggest that the average speed at which a road delivers maximum capacity is 40 miles per hour.

This is because as speed increases the distance between cars needs to increase to accommodate reaction times and stopping distance.

The same applies in wireless devices - as data rates increase the devices need more road room/network space - expressed in this example as code bandwidth but similar arguments could be made that time domain burst shaping within the transmit time template also becomes harder to manage.

Additionally the driver in the Bugatti needs a finely developed ability to decide when a gap becomes available and how long that gap will be available. This includes mind reading all the Beetle owners who will be thinking of filling the gap themselves. This is directly analogous to the channel measurement and load measurement and signalling bandwidth needed to manage devices with differential performance.

For example an advanced receiver in an HSPA terminal (using diversity and enhanced equalisation) will typically report a higher channel quality indication than a conventional Rake receiver

This would mean the terminal could be given preferential access to available bandwidth - permission to use the fast lane.

However the fast lane may be needed for other slower users with a higher priority - Beetles with an emergency to attend. Arbitrating these access policy decisions is complex and consumes time, power and bandwidth.

The Bugatti handset could have a number of performance advantages over the Beetle handset. It could have improved stability (more accurate clock references), better sensitivity and selectivity - a composite of better filter Q, higher Q oscillators and more optimised power and noise matching.

It can be argued that Beetles become more like Bugattis over time. The performance of a Beetle today is similar to the performance of an original Bugatti 70 years ago.

However you could probably go from Brooklands to Biggin Hill faster in the 1930's in your Bugatti than you could today via the M25 - the Beetle and Bugatti are equal partners in a traffic jam though the Bugatti will waste more fuel in the queue.

Effectively we are saying that high performance terminals do not benefit network capacity in a linear manner and that the overall capacity of networks on a per MHz basis has not increased nearly as dramatically as the headline figures would suggest.

The answer of course is to make roads wider but this has a cost both in terms of capital expenditure on land (spectrum), tarmac (RF and backhaul hardware) and operational expense.

Macro scheduling as a solution

The other option is to try and spread users out more evenly across the day.

This can be done by road pricing (differential tariffing).

But at this point the motoring metaphor breaks down.

In wireless, specifically in cellular wireless networks, there might typically be five operators, two or three of whom could be co sharing spectrum.

This is analogous to having three M25 motorways side by side with the limitation that users cannot move between motorways when congestion occurs.

Intuitively operators want to hold on to every bit of traffic that arrives on the network.

There is however an argument that there is an increasing need to differentiate between users in the right place at the right time and users in the wrong place at the wrong time.

This is true both in terms of time and space. We have said earlier that it can be inconvenient and expensive to service a user with high data rate expectations at the edge of a cell.

The user will be occupying maximum code bandwidth on the downlink and will be at maximum power on the uplink which will desensitise the adjacent cell.

That user could of course be close to a base station operated by a competitive operator. It would be more profitable to shed that load to that operator rather than to compromise the performance of other physically and spectrally proximate users.

In essence **users in the right place at the right time generate profitable offered traffic.**

Users in the wrong place at the wrong time generate unprofitable offered traffic.

This implies a shift in thinking in the operator community and the adoption of a more embracing approach to the principle and practice of inter network handover algorithms to solve coverage and/or capacity problems.

Present constraints on capital expenditure and operational expense suggest that this approach will become more attractive over time.

Why the Beetle is better than the Bugatti

Rushing at things never really works. The headlong stampede to deploy packet networks has not delivered the expected step function increase in capacity neither has it generated the expected step function increase in revenues.

High data rate terminals will only deliver a linear gain in network capacity if coupled with a linear increase in network capacity and network density.

Traditional telecom operators and telecom vendors know this and realise that user expectations can only be satisfied through substantial additional investment in network hardware, specifically radio and backhaul capital spending.

If the money is not available for this investment then some other solution has to be found. Inter network handovers are arguably one part of the solution.

The Bugatti is a beautiful piece of engineering but its full performance potential can only be realised on a test track with no other motor cars in sight.

If we all owned Beetles and had at least three routes we could take to work and could change route at will depending on congestion and available speed limits (data rates in our analogy) then journey times would be significantly shorter.

The Beetle and multiple routing including inter network routing provides a composite and potentially fiscally efficient solution to the wireless data jam.

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