RTT TECHNOLOGY TOPIC
June 2015

The impact of backhaul on 5G network economics

This month we look at the impact of backhaul performance on 5G mobile broadband network economics.

Backhaul has always been and will continue to be a critical part of mobile broadband networks.

Self-evidently backhaul bandwidth needs to keep pace with the growth in mobile broadband traffic but this is only part of the picture. Many 5G studies focus on new wide area physical layer options including spectral or power efficient modulation and coding schemes but in practice mobile broadband network economics are substantially determined by scheduler efficiency.

Scheduler efficiency is determined by a combination of access control and dynamic allocation of bandwidth in the time, frequency, power and spatial domain.

Dynamic bandwidth allocation has to be managed at sub frame level every millisecond. This is more onerous than legacy scheduling which is either implemented every frame (10 milliseconds) or every other frame (20 millisecond semi persistent scheduling for voice).

This means that in LTE Advanced and 5G networks, microseconds of additional backhaul delay and delay variability particularly on the control plane (signalling bandwidth) will have a significant impact on mobile broadband network efficiency and network economics.

Put more positively, any reduction in backhaul delay or delay variability should translate into more capacity and a better user experience. Note that scheduling can be optimised for throughput (maximum efficiency) or cell edge performance (optimum quality of service). The trick is to achieve the optimum compromise between these two not entirely complementary objectives – a bit like getting an optimum match on a Smith chart. It is backhaul performance that determines how effectively this compromise point can be achieved and maintained.

Backhaul bandwidth therefore needs to be designed to ensure that end to end delay and delay variability is kept to a minimum. This requires careful and cautious implementation of channel coding and error correction. It also implies that backhaul bandwidth has to be provisioned to avoid buffering under all load conditions including traffic peaks.

This raises the question as to whether backhaul should be implemented as a relay or repeater.

Relay hops demodulate and decode user and signalling traffic. This has the advantage of reducing end to end bit error rates, a function of the modulation and coding gain. The cost however is the delay involved in demodulating and decoding then modulating and coding the backhaul then performing the reverse process at the other end.

An alternative is to bring backhaul in band and treat backhaul as a repeater system rather than a series of relay hops. The coding gain disappears but then so does the modulation and coding latency.

Bringing backhaul in band would also mean that mobile broadband scale economics could be applied to the presently fragmented backhaul product sector. Making the link a repeater link rather than a relay would reduce cost further.

The combination of lower cost hardware and the performance gain that this would achieve though improved scheduler efficiency might be exactly what 5G needs to become economically viable.

Earlier technology topics this year have looked at the emerging band plan options for 5G including allocations in the Centimetre Band (between 3 GHz and 30 GHz) and Millimetre band (30 to 300 GHz).

These allocations will either overlap or be directly adjacent to other radio systems including point to point and point to multipoint backhaul.

The industry has two choices. Either there can be endless disputes as to whether or how existing fixed wireless and backhaul bandwidth should or could be repurposed for mobile broadband or there could be a sensible debate as to whether a co sharing and integration model could deliver technical and commercial gain to all involved parties.

Read on

Backhaul band allocations are every bit as complicated as LTE band allocations. The Metre band (300 MHz to 3 GHz) includes 1.4 GHz licensed links using Yagi antennas to provide terrestrial DAB and utility point to point and smart grid connectivity. The 2.4 GHz ISM band is also used, co sharing with Wi Fi.

The Centimetre band includes unlicensed point to point in the 5 GHz Wi Fi band and licensed bands at 11,13,15,18, 23, 26 and 28 GHz.

The Millimetre band includes unlicensed point to point in the 60 GHz Wi Fi band and licensed or lightly licensed bands at 32 GHz, 38 GHz, 40 GHz, 42 GHz,45 GHz, 52 GHz, 55 GHz, 65 GHz,70 GHz (the 71-76 GHz band), 80 GHz(the 81-86 GHz band) and 90 GHz (92-95 GHz).

These bands are allocated on a country by country basis with little regional harmonisation either in terms of band plan or physical layer implementation.

In the Metre band, a 1.4 GHz link would typically use 32 level QAM producing a peak throughput of 9 Mbps per 3.5 MHz channel within a 24 MHz pass band.

In the Centimetre band, licensed link equipment at 28 GHz might typically use 512 QAM to deliver 400 mbps peak throughput though a 56 MHz channel with 38 dBi of gain from a dish antenna.

In the Millimetre band, licensed link equipment at 38 GHz would typically use a 28 MHz channel with 1024 QAM to give a gross bit rate of 250 Mbps per channel with channel aggregation (for example to 56 MHz) to support 500 mbps. Higher antenna gain (>50 dBi) helps the link budget.

A 42 GHz or 70 to 80 GHz band might typically be implemented with 112 or 250 MHz spacing. A single 112 MHz channel at 42 GHz should support a gross bit rate of 1 gbps using 1024 QAM modulation. A 70 or 80 GHz link could have four x 250 MHz channels aggregated together – one GHz of bandwidth supporting one gbps of data throughput.

Small cell backhaul today has a typical peak bandwidth requirement of 100 to 200 mbps. The general assumption is that this will increase to around 1 gbps for LTE-A/Wi Fi backhaul. This order of magnitude increase might seem scary but should be supportable on the basis of the combination of additional band allocations and higher order 2048 QAM and 4096 QAM modulation schemes.

Meeting latency budgets may however be trickier.

4G and 5G mobile broadband networks are increasingly dependent on link adaption mechanisms to achieve scheduler efficiency. From an operator perspective, scheduler efficiency is a proxy for cell spectral efficiency. From a user perspective; the scheduler also has to deliver acceptable cell edge performance. Achieving these conflicting objectives is dependent on close control of the feedback mechanisms that determine admission control.

In HSDPA, the scheduler allocates time domain and code domain resources but always occupies the full (5 MHz) channel bandwidth.

In LTE, admission control is also performed in the frequency domain implemented at resource block level. A resource block is 12 X 15 KHz sub carriers giving a resource block bandwidth of 180 KHz. In the time domain, the basic frame length within LTE is 10 milliseconds. Voice is supported with semi persistent scheduling every 20 milliseconds but from Release 10 onwards, data is scheduled at each one millisecond sub frame with additional scheduling possible at each of the two slots (0.5 milliseconds) within the sub frame. The dynamic allocation of resource blocks is usually described as frequency domain scheduling but is in practice a combination of frequency domain and time domain bandwidth allocation.

Interference management in the time domain is implemented at sub frame level.

In the frequency domain, resource block sub carriers can be allocated on the basis of channel quality (channel dependent scheduling) or can be chosen to minimize interference to other users or adjacent radio systems; reduction of OOB emissions is an example.

Interference management is implemented in the code domain with orthogonal cover codes to support different layers of spatial multiplexing and to discriminate between different terminals shared on the same resource within a cell or in neighbouring cells.

Interference management in the power domain remains an open debate, at least for 5G networks.

Close control of transmit power from user devices has been a fundamental part of cellular voice network design for over 30 years. The principle is that mobile devices should never use more power than needed to overcome path loss. This has been an effective way to manage interference and has generally helped increase user battery life.

Schedulers now have the option of operating devices at a fixed power output and changing the amount of available resource block bandwidth to accommodate variable traffic rates.

Alternatively physically and spectrally efficient user devices can be run at different power levels with interference cancelled out by using successive interference cancellation at the e Node B. This is usually described as non-orthogonal multiple access (NOMA).

Last but not least, interference can be managed in the spatial domain by the use of antenna beam forming combined with various options of transmit diversity and spatial multiplexing.

Admission control decisions including frame by frame changes in coding and modulation are made by groups of eNodeB’s co sharing the information needed. The decisions include handover, load management, interference management and network and mobility optimisation. This is done over the X2 interface.

The legacy rule of thumb on end to end signalling delay is that 10 milliseconds round trip delay is acceptable and 5 milliseconds desirable.

This might be acceptable for Release 8 inter cell interference coordination which provides semi static coordination of resources every few seconds.

It is not adequate for LTE Advanced scheduling/beam forming which potentially requires the dynamic coordination of frequency, time, power and beam forming resources at sub frame level.

The signalling bandwidth is relatively trivial (less than 1 mbps!) but delay or delay variability on the X2 interface translates directly into reduced scheduler efficiency.

This brings us back to the issue of future backhaul requirements.

The delay budget on a well-designed point to point radio is of the order of 250 microseconds which could be regarded as trivial but fails to take into account buffering delay including the delay of taking traffic and signalling off the mobile broadband network and modulating and demodulating and encoding/decoding over the backhaul link.

The backhaul is therefore functioning as a relay. This has the benefit of improving the signal to noise ratio but has the disadvantage of introducing additional delay and delay variability.

It may therefore be more appropriate for backhaul systems to function as repeaters rather than relays. Repeaters for example are now (more or less) standardised within the LTE specifications.

Additionally there may be merit in considering bringing backhaul in band to allow wide area mobile networks to co share point to point bandwidth in the centimetre and millimetre bands.

This would have scale economy and functional benefits. With the exception of the 23 and 38 GHz bands, all other licensed and lightly licensed point to point bands are sub scale making it hard to justify the development of lower cost higher performance component and packaging technologies such as surface mount GaAs PHEMT MMICS. Adding mobile broadband volume to these bands would help resolve component cost and performance issues.

Bringing back haul in band would also imply a rationalisation of the present combination of higher layer TDM, ATM, IP, Ethernet, IP over Ethernet and related IEEE1588 PTP transport and timing protocols.

It is however hard to see how else the latency requirements and technical and commercial requirements of advanced 4G and 5G networks can be met.

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