realwireless
independent wireless experts

Consideration of Uplink Coverage Limitations

www.realwireless.biz

© Real Wireless Ltd. 2012

Introduction

- Ofcom modelling of LTE networks was based on the downlink only and did not consider the uplink
- Here we consider the performance of the uplink in comparison to the downlink and consider whether it may be a limiting factor for performance or coverage.
- The following questions are addressed:
  - **A.1** What minimum uplink data rate is necessary for maintenance of a downlink connection?
  - **A.2** Given that TCP is a key protocol for internet traffic, is there is a certain data rate in the uplink to support a particular downlink data rate? Specifically, does the uplink rate need to be, at minimum , a particular percentage of the downlink rate to ensure adequate TCP performance?
  - **A.3** Allied to A.2, how many resource blocks would need to be used in the uplink?
  - **A.4** From an implementation point of view, is there a minimum number of resource blocks that must be used in the uplink, and is this likely to change?
  - **A.5** For the assumed number of uplink resource blocks, can the entire carrier power be allocated to these?
  - **A.6** The uplink mapping function of 3GPP 36.942 Annex A Section A.1 gives an uplink SINR cut-off of -10 dB . Is this a suitable reference for the cut-off value?

© Real Wireless Ltd. 2012

A1: Basic UL connectivity

A.1 What minimum uplink data rate is necessary for maintenance of a downlink connection?

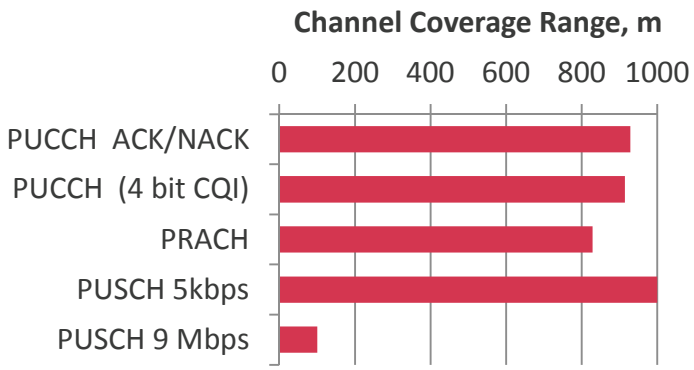
- As in the case of the downlink, the uplink comprises both control channels needed for basic connectivity, and a data channel with capacity increasing with signal quality.
- Here we consider the signal quality required for the control channels, as well as that required to achieve a given data rate.
- We refer to uplink coverage analysis in the following texts:

[Sesia] "LTE the UMTS Long Term Evolution", S. Sesia, I. Toufik, M. Baker, Wiley 2009
[Holma] "*LTE for UMTS: Evolution to LTE Advanced*", H. Holma, A. Toskala, 2nd ed., Wiley 2010

© Real Wireless Ltd. 2012

A1 Sesia on UL Coverage

- Overall UL coverage requires minimum performance achieved on a number of physical UL channels:
- PUCCH (Physical Uplink Control Channel)
  - ACK/NACK <1% probability of false ACK
  - CQI (multiple formats exist), FER<1%
- PRACH (Physical Random access Channel)
  - Range for <1% PER
- PUSCH (Physical Uplink Shared Channel)
  - Carriers User plane data.
  - Range depends on require rate.
    - A minimum 5kbps (1RB) exceeds range of all other channels
    - A maximum 9.2Mbps has much shorter range



Range of coverage of uplink control and data channels. Source: "LTE the UMTS Long Term Evolution", S. Sesia, I. Toufik, M. Baker, Wiley 2009

- **Basic connectivity of the control channel has similar coverage to a very low data rate of just over 5kbps**

© Real Wireless Ltd. 2012

A1 Required Performance and channel quality

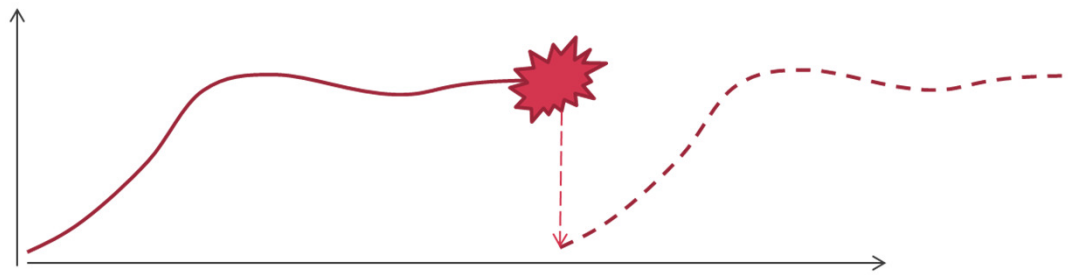
- Required channel performance is defined in terms of probability of missed detection or erroneous interpretation of ACK or NACK etc.
- Required signal qualities are given in terms of E_S/N_o
  - Symbol energy to noise spectral density is SNR normalised to a symbol, so is *transmission* bandwidth independent.
- Range comparisons in [Sesia] show UL PUCCH can have similar coverage to the DL Broadcast channel (PBCH)
  - *"The 1 bit ACK/NACK and 4bit CQI formats fall short of PBCH coverage by 1.3dB"…*
  - *"A repetition factor of 2 can be used to close the coverage gap"*
- **Coverage range of basic connectivity for UL seems similar to DL - it will therefore be data rates that determine whether coverage is DL or UL limited**

© Real Wireless Ltd. 2012

A1 Holma on UL coverage

- Coverage analysis in [Holma] does not explicitly consider the control channel requirements in the link budget
- It considers only the -7dB SINR required to maintain a 64kbps connection using 2 RBs (this is consistent with the -8.8dB SINR required to maintain a 5kbps connection given in [Sesia])
- Max path losses with 1Mbps/64 kbps DL/UL are very close with LTE
  - 1Mbps Downlink can tolerate 163.5dB path loss
  - 64kbps Uplink can tolerate 163.4 dB path loss
- For higher UL rates, the UL would limit coverage (and the same for DL)
- 1Mbps/64kbps is a 1:16 ratio: UL is 6.4% of DL
- **This suggests that if the UL rate is more than ~6% of the DL, then coverage would be UL limited (in a noise limited scenario)**
  - Noting that interference for a UE is independent on the UL and DL

© Real Wireless Ltd. 2012



A.2 LTE Asymmetry and TCP Performance

A.2 Given that TCP is a key protocol for internet traffic, is there is a certain data rate in the uplink to support a particular downlink data rate? Specifically, does the uplink rate need to be, at minimum , a particular percentage of the downlink rate to ensure adequate TCP performance?

Company Confidential © Real Wireless Ltd. 2012

A2 TCP - Introduction

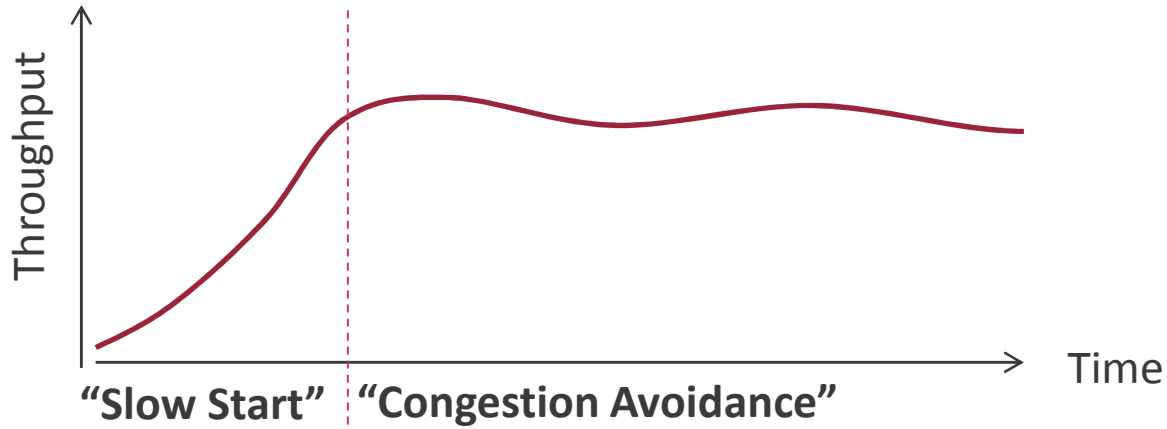
- Internet protocol used when **reliable** or **sequenced** data delivery is required
- Used as a transport for HTTP (ie web traffic including Flash video etc.)
  - Expected that very high percentage of traffic will be TCP for most users
  - 2009 study shows TCP is ~90% of Internet traffic by volume [3]
- TCP transmitter attempts to adjust rate of sending to make best use of transmission bandwidth available without overloading network
  - Adaptive behaviour is not fully standardised – much is implementation specific
  - Much research and standards work pointing out suggested or recommended adaptive behaviour.
  - Nature of adaptive algorithms changes due to research/improvement
- TCP receiver acknowledges received data with "ACK" packets
  - Provides reliability by detecting lost data
  - Used by transmitter to make estimates about performance of the connection

[3] http://www.caida.org/research/traffic-analysis/tcpudpratio/

Insufficient bandwidth for ACKs degrades TCP performance

Company Confidential © Real Wireless Ltd. 2012

A2 TCP Connection Phases



Transmitter will:

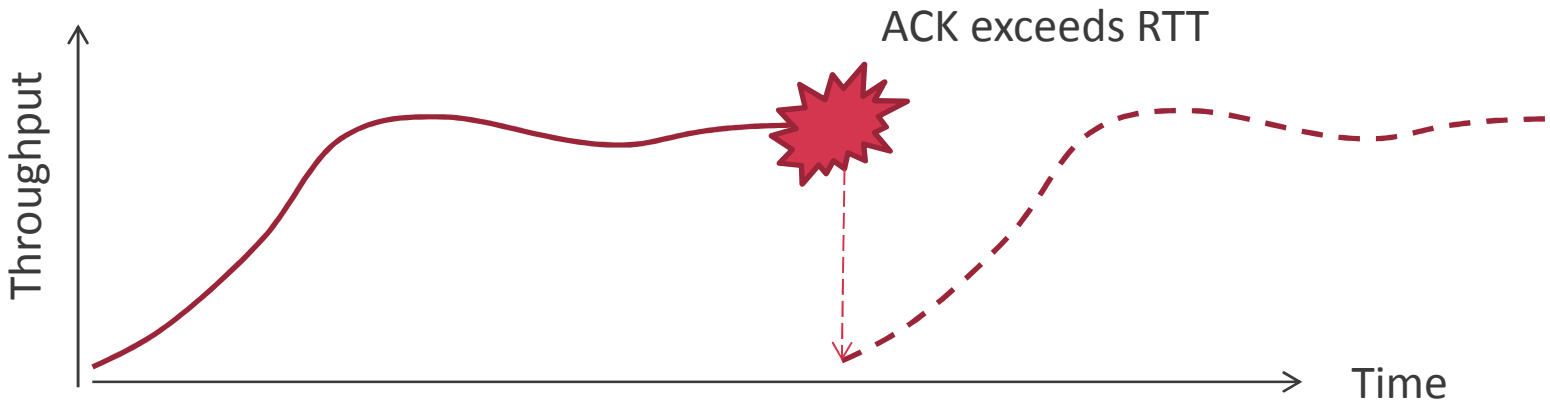
- Increase transmission rate to "feel" connection characteristics
- Use receipt of ACKs to trigger transmission of new packets and quickly increase size of transmit window leading to rate increase

Transmitter will:

- Gradually adapt rate to match (possibly changing) character of channels
- Use ACKs to provide input data to this adaptation
- Changes not as aggressive as in slow starts

Company Confidential © Real Wireless Ltd. 2012

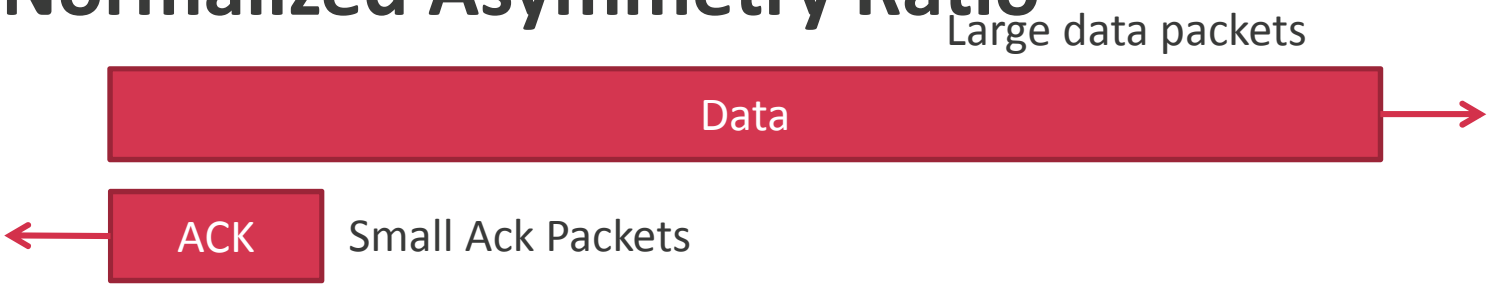
A2 Lost packets and ACKs



- Transmitter will make an estimate of the round trip time (RTT) and its variation
- Data not acknowledged within an implementation dependent multiple of the RTT estimate may be assumed to be lost
  - Some implementations assume that all loss is due to congestion
- Detected congestion will make transmitter more conservative in its sending rate
- Implementations may go back to “Slow Start” mode if they detect a lost packet/ACK

Company Confidential © Real Wireless Ltd. 2012

A2 Normalized Asymmetry Ratio



- Academic studies on TCP performance on asymmetric links introduce concept of “normalized asymmetry ratio”
- Normalized Asymmetry ratio = ratio of raw bandwidths on both directions to the ratio of packet sizes in both directions
- Uplink can be smaller than downlink because ACKs are smaller than data

Company Confidential © Real Wireless Ltd. 2012

A2 Asymmetry vs. Object Transfer Time

- Hasegawa et al investigate transfer times of file sizes from 10kbyte – 10,000 Kbyte over links of various asymmetry described by factor k
  - k= BW ratio / packet size ratio
- Transfer times in most cases are minimal for around k=8
  - This paper assumes a packet size ratio of a 40 byte UL ACK to 1KB DL data i.e. 1:25 or 4%
  - K=8 corresponds to a BW ratio of 8x25 = 200
- So in this case UL traffic is 0.5% of DL
- The paper is quite old and TCP implementations might be different to those used today

Source: "Performance evaluation of HTTP/TCP on asymmetric networks", Go Hasegawa, Masayuki Murata and Hideo Miyahara, 1999, http://goo.gl/nMPr8

© Real Wireless Ltd. 2012

A2 Ericsson Simulation of impact TDD Asymmetry on file download performance with TCP [1]

- Simulation is for LTE-TDD but broadly illustrates what would be expected for any asymmetric channel
- At high DL:UL ratios the “Slow Start” phase of TCP performs poorly due to poor ACK performance
  - 1M files perform worse on 9:1 link than on 4:1 link despite more DL bandwidth
- “Congestion Avoidance” phase less impacted by ACKs and larger files use available DL capacity better despite asymmetry

[1] Riikka Susitaival, Henning Wiemann, Jessica Östergaard, Anna Larmo: “Internet access performance in LTE TDD”. IEEE Vehicular Technology Conference (VTC 2010-Spring), 2010

Company Confidential © Real Wireless Ltd. 2012

A2 Live Demonstration of FTP Transfer shows ~2%

Photo taken 27/6/2012,
Small Cells World Summit

- A vendor at the Small Cells World Summit conference, June 2012 was demonstrating over the air file transfers of just over 100Mbps (using FTP, which in turn uses TCP)
- In this example, the uplink traffic required to support this was just over 2Mbps (2%)

© Real Wireless Ltd. 2012

A2 ADSL Experience

Standard	Common Name	Max DL Speed	Max UL Speed
G.992.1	ADSL	12Mbit/s	1.3Mbit/s
G.992.2	ADSL Lite	1.5Mbit/s	0.5Mbit/s
G.992.3	ADSL 2	12Mbit/s	1.3Mbit/s
G.992.5	ADSL 2+	24Mbit/s	1.3Mbit/s
G.992.5 Annex M	ADSL2+M	24Mbit/s	3.3Mbit/s

- ADSL often operates in highly asymmetrical configurations
  - 10:1 ratios are not uncommon in real deployments
- Proposed US "Universal Service" requirement: 4Mbit/s DL, 1Mbit/s UL

10:1 asymmetry seems acceptable for ADSL users

Company Confidential © Real Wireless Ltd. 2012

A2 Summary – UL traffic required to support DL

source	Implied UL traffic as %DL	Comment
Stakeholder Response	4%	Equal to typical packet size ratio ACK:Data
[Hasegawa] http://goo.gl/nMPr8	0.50%	old TCP implementations – may be out of date
Live Demo	2%	Live demo of file transfer (FTP) over commercial LTE products
ADSL	10%	typical ADSL asymmetry factor seems to work
Ericsson [1]	>11%	TD-LTE UL:DL ratio shows 4:1 optimal for 1MB file size, but 9:1 ok for 10MB file.

- TCP will be a critical protocol for most users and is expected to be the overwhelming majority of user traffic
- Uplink bandwidth and latency is expected to impact TCP performance
- Experience will play a large part in determining DL/UL ratios required
- A range of ratios is summarised in the table, from 0.5% to over 11%
  - The numbers sit either side of the 6% figure shown earlier for balanced UL and DL coverage
  - However, operators may use TCP optimizers to mask radio effects and LTE may perform differently from HSPA
- Acceptable UL performance might not be determined solely by the ACK traffic for DL TCP – what is an acceptable rate for UL TCP, gaming or other services, for example.

© Real Wireless Ltd. 2012

A3 RBs needed to support given UL data rate

A.3 Allied to A.2, how many resource blocks would need to be used in the uplink?

- UL Data rate depends on:
  - No. simultaneous RBs in frequency domain (over which UE tx power is spread)
  - No. RBs per second in time domain (every TTI, or 1 in N TTIs)
  - No. information bits per RB (depends on modulation and coding rate, and thus SINR)
- Power control mechanism is used to set target SINR for a UE, and fairness policies may impact individual UEs' SINRs
- We note that more simultaneous RBs means less power per RB, and thus reduces the path loss that can be tolerated

© Real Wireless Ltd. 2012

A3 Optimal Number of RBs for Given Data Rate

- [Holma] shows that the number of RBs for optimal coverage depends on the rate required:
  - <100kbps → 2RBs
  - 100 - 360kbps → 6 RBs
  - >360 kbps → 25 RBs
- Intermediate numbers of RBs are also possible and each would provide optimal coverage at a particular data rate
- It is claimed that the mechanism behind this is improved channel estimation for the lower rates due to the narrower bandwidth
- **This shows for UL data rates of 64kbps and above, optimal coverage is achieved with 2 or more RBs**

© Real Wireless Ltd. 2012

A4 Minimum number of RBs for the UL

A.4 From an implementation point of view, is there a minimum number of resource blocks that must be used in the uplink, and is that position likely to change?

- **Control Channel PUCCH:**
  - When there is no data to send, the UE may transmit control information (PUCCH) on the outer edges of the channel in a single RB transmission
- **Data channel (PUSCH)**
  - 36.211 shows the Bandwidth of PUSCH in terms of resource blocks, is defined as:
    - MRBs = $2^a.3^b.5^c$
  - So using a=b=c=0 gives a 1 RB allocation
- The uplink link budget in [Holma] shows that 2RBs are used for a 64kbit rate
- However, for 256kbps rate, [Holma] suggests that optimal coverage would be achieved with between 6 and 25 RBs, so concentrating power into a single RB may not be appropriate
- The following paper also shows that PUSCH allocations of 1RB are possible:
  - "*Uplink Power Control in UTRAN LTE Networks*", pp178, Proceedings from the 7th International Workshop on Multi-Carrier Systems & Solutions, May 2009, Herrsching, Germany, http://goo.gl/UHxp7

© Real Wireless Ltd. 2012

A5 Concentrating all UE power into one RB

- A.5 For the assumed number of uplink resource blocks, can the entire carrier power be allocated to these?
- As shown previously 1RB allocations are possible within the 3GPP specification 36.211
- Another 3GPP document considers concentrating full power into 1RB (at the channel edge) as a potential worst cases for unwanted emissions
  - "Spectrum Emissions Mask considerations for LTE UE", Ericsson, 3GPP Tdoc R4-070382, April 2007

- **These both suggest the entire carrier power can be concentrated into a single resource block**

© Real Wireless Ltd. 2012

A6 3GPP 36.942 as a source for uplink SINR cut-off

A.6 The uplink mapping function of 3GPP 36.942 Annex A Section A.1 gives an uplink SINR cut-off of -10 dB . Is this a suitable reference for the cut-off value?

- SINR mapping functions in 36.942 were intended for use in co-existence studies to represent the general behaviour of link adaptation mechanisms
  - The SINR cutoff is only representative and is therefore was not intended for coverage analysis which is highly sensitive to this value.
- There are other studies shown in A1 which provide a more accurate view of the minimum signal quality required to maintain a connection
  - [Sesia] shows UL SINR cutoff is -7.5dB for a basic connection with just over 5kbps
  - [Holma] shows -7dB SINR needed to provide basic 64kbps UL over 2RBs
  - Higher UL data rates would require higher SINR

© Real Wireless Ltd. 2012

Conclusions on Impact of Uplink

- Ofcom's coverage analysis considers only the downlink. We can envisage scenarios where the UL might limit coverage
- Coverage generally reduces with the required data rate. However we can also consider the signal quality needed to maintain basic connectivity with a zero or negligible data rate. Sesia shows this is -7.5dB for the UL.
- TCP traffic on the DL requires ACK signalling on the UL. Various sources suggest UL rates of between 0.5% and 11% of the DL
  - Acceptable UL performance might not be determined solely by the ACK traffic for DL TCP
- Holma's coverage analysis shows that rates of 1Mbps DL and 64kbps UL result in a balanced connection that can tolerate equal path loss on both UL and DL
- Although LTE UEs are capable of transmitting their power over any number of RBs, for UL data rates of 64kbps and above, optimal coverage is achieved with 2 or more RBs

© Real Wireless Ltd. 2012

realwireless

independent wireless experts

Contact

Real Wireless
PO Box 2218
Pulborough
West Sussex
RH20 4XB
United Kingdom

Tel: +44 (0) 207 117 8514
Web: www.realwireless.biz
Blog: realwireless.wordpress.com
Email: info@realwireless.biz

realwireless.biz