COMPARISON BETWEEN LTE AND RIVAL WIRELESS TECHNOLOGIES

ENSC 427: Communication Networks. Spring 2013

Abstract

Long-term-evolution (LTE) is a fourth generation (4G) wireless network for mobile devices. LTE is the natural successor to HSPA+ 3G networks, providing higher data rates, lower latency and a simplified architecture. We have explored the claims made by LTE as a superior technology through simulation of LTE against rival wireless technologies such as WiMAX and Wi-Fi. Using Opnet16 software package, we measured and compared throughput, spectrum efficiency, delay and jitter when transferring a custom stream of data. Based on the results, we were be able to make positive conclusions about the validity and extent of LTE's superiority over its rival wireless communication technologies.

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Introduction & Goals

Access to the internet became an easily fulfilled necessity in a contemporary world. With a variety of devices offering modern radio capabilities, there exists a variety of technologies that provide mobile data transfer. Our goal is to compare the 4th generation LTE technology to its 4G rival WiMAX and to an older, but constantly improving Wi-Fi technology. Modern wireless and mobile communication devices support at least one of the three and we would like to determine whether LTE has the potential to emerge as the next leading digital communication technology in terms of speed and quality of transmission. By using Opnet16 software package, we were able to compare the technologies in a variety of tests.

Background: The overview of technologies

LTE

LTE stands for Long Term Evolution and it is currently a leading 4th generation standard for wireless mobile communication and data transfer. Our focus is on the Release 8 of 3GPP, which is the basic version of the technology. 3GPP Release 10 is LTE Advanced technology, which increases the performance even further. Long Term Evolution is based on its predecessors (3G technologies such as HSPA+), but offers improvements in the following key aspects of interest:

-Maximum data rates: 300 Mbit/s DL (MIMO) and 75 Mbit/s UL (versus 172 Mbit/s DL and 23 Mbit/s UL of best HSPA+ versions)

-Connection set up time (from idle to connected mode): LTE MIMO has approximately 3.4 times lower connection time than HSPA+ SIMO using 64QAM modulation scheme (one of the fastest versions)

-Latency in connected mode: LTE MIMO has approximately 1.6 times lower latency than HSPA+ SIMO 64QAM

-Lower complexity of the overall technology compared to UMTS (HSPA+, GPRS, etc) technologies partially due to the removal of the circuit-switched parts of the network.

Possibly the largest evolvement from the 3G technologies is the fact that LTE is purely IP based. In other words, there is no use of circuit-switching anymore. The base stations, evolvedNodeB's (eNB) are interconnected forming a flat network architecture with "intelligence" distributed across them. This network is connected to the IP-based Evolved Packet Core. LTE eNB can support an area of at least 50km^2.

One of the distinguishing features of LTE is the use of Orthogonal Frequency Division Multiple Access for the downlink. While LTE is not the first technology to use OFDMA, the use of this technique is one of the features allowing for the high performance of LTE. In particular, OFDMA provides high robustness against frequency selective fading, low-complexity implementation and spectrum flexibility. Other aspect partially responsible for high data rates is the use of Multiple Input Multiple Output spatial multiplexing. MIMO is implemented by having multiple transmission antennas at the eNB and multiple receiver antennas at the UE (User Equipment).

WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a rival wireless communication standard capable of meeting 4G requirements as a mobile communications technology. WiMAX uses a Scalable-Frequency Division Multiple Access, which is a variation of OFDMA. The latest revision, the 802.16m is capable of delivering up to 219 Mbit/s DL with 4x4 MIMO (as opposed to LTE's 300 Mbit/s on 4x4 MIMO). The UL can support up to 140 Mbit/s data rates. Aggregation of channels in WiMAX 802.16m is also possible, where multiple channels can be occupied to increase the effective bandwidth up to 5 times. This will increase the data rate, but not the spectrum efficiency. In its most basic implementation, a WiMAX network has SS (Subscriber Stations) connected to a BS (Base Stations), which are connected to an IP backbone network. In its mobile configuration (which is the case in our study), WiMAX cell can support data rates to users in a 20km^2 area.

Wi-Fi

Wi-Fi is a wireless implementation of a Local Area Network for computers (WLAN). IEEE 802.11 set of standards describes and governs this technology. While it was never intended to be a mobile network, most mobile equipment these days has Wi-Fi capabilities. Given the fact that it is wireless, we decided that it is a legitimate rival to LTE and WiMAX. The latest version of Wi-Fi (802.11n) can provide data transfer rates of up to 150Mbit/s, using the Frequency Division Multiple Access (same as LTE and WiMAX) and it has support for MIMO. The latest version supported by Opnet 16 is 802.11g with 54 Mbit/s with SISO. In its simplest implementation, a user of a Wi-Fi enabled equipment can connect to an access point within the range, which is connected to the internet. It should be noted that the typical range of Wi-Fi access point does not exceed 0.2km.

Project Setup

For our project we created three separate Opnet 16.0 projects to simulate and compare Wi-Fi, WiMAX and LTE technologies. We started with Wi-Fi technology, because it was the simplest technology to implement and configure. We, additionally, had to wait for WiMAX and LTE Opnet licenses to be installed which contributed to our decision to start with Wi-Fi. We used the Wireless Deployment Tool in Opnet to create a wireless network with 5 fixed mobile nodes in circular topology around a single wireless access point. The physical scale was set to office with area of 200x200 metres. We chose this scale to compare the three technologies fairly as Wi-Fi's range is more limited than WiMAX and LTE. By using a small scale we also removed signal strength and quality as variables in our comparison by giving ideal values to all technologies.

We chose simple Ethernet server to act as a traffic source and we configured it's attributes to support all services. To connect the server to our wireless access point, we used Cisco 7200 switch, connected to the IP backbone, which, in turn, is connected to the Access Point (in case for Wi-Fi network topology). The reason we chose this specific switch is simply because it has all necessary connections to act as a bridge between the Ethernet server and the IP backbone. The OC-12 fibre cable was used in connections between the access point, IP backbone and the switch. This cable is commonly by Internet service providers and has a sufficiently large bandwidth to not be a limiting factor in our simulation. The connection between Cisco 7200 switch and the Ethernet server was established using Gigabit Ethernet cable.

We specified a custom Modified Video Conference application to be used across the three technologies that we simulated. The application uses custom incoming frame size that we defined in the input file. In addition, we set constant small outgoing frame size. In the Profiles configurations we applied Modified Video Conference application under the custom profile that was used in our simulation for the three technologies. The created custom input file contains indexed frame sizes to simulate linearly increasing bit rate. That allows us to measure the throughput at which the three technologies become saturated and make a comparison.

We changed AP Transmit power and Mobile Node Transmit Power to 1.0 W and 0.1 W respectively to provide ideal situation for signal transmission and any additional limitations related to signal strength. Furthermore, we set the AP and Mobile Node Buffer sizes to 1024 Kbits.

All the technologies were set to utilize 20 MHz bandwidth to measure their peak performances.

The screen cap below illustrates our setup for wireless network topology.

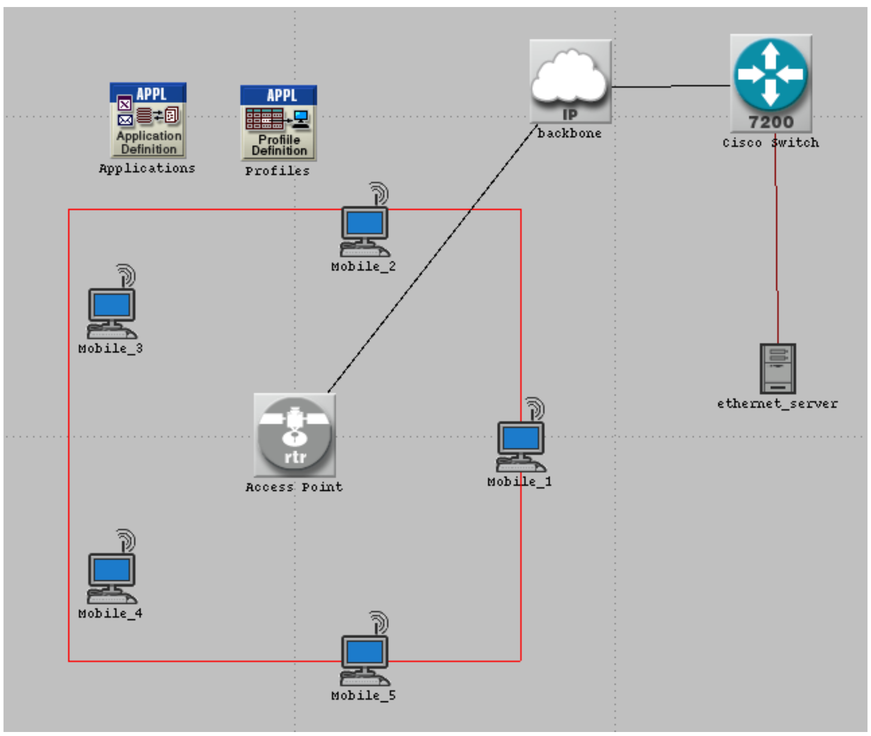


Figure 1: Wi-Fi Topology

To create WiMAX network topology, we, once again, used the Wireless Network Deployment Tool with the same settings as used for Wi-Fi. The only difference is that instead of using the access point and five fixed mobile nodes we now have Base Station (BS) and five fixed Subscriber Stations (SS). As was stated before, we used the same application and profile configuration with the same custom input file to be able to compare the results from our simulations in the same environment for all three technologies.

Efficiency mode was enabled for WiMAX simulation because we ran into issues configuring the physical layer parameters. In the interest of time and limited need for a full physical simulation we decided to opt for efficiency mode for WiMAX.

In WiMAX configuration we specified a custom service class that we named "Video Class", which utilizes rTPS scheduling. Subscriber Station and Base Station Classifier definition was set to assign all traffic to the Video Service class. In addition, for SS (downlink and uplink) we assigned service flow service class to the "Video Class". Subscriber Station downlink modulation scheme was set to 64-QAM 5/6, since it allows us for maximum throughput as shown in Figure 2. Uplink modulation scheme was set to QPSK 3/4.

The figure below shows the comparison between different modulations scheme using WiMAX.

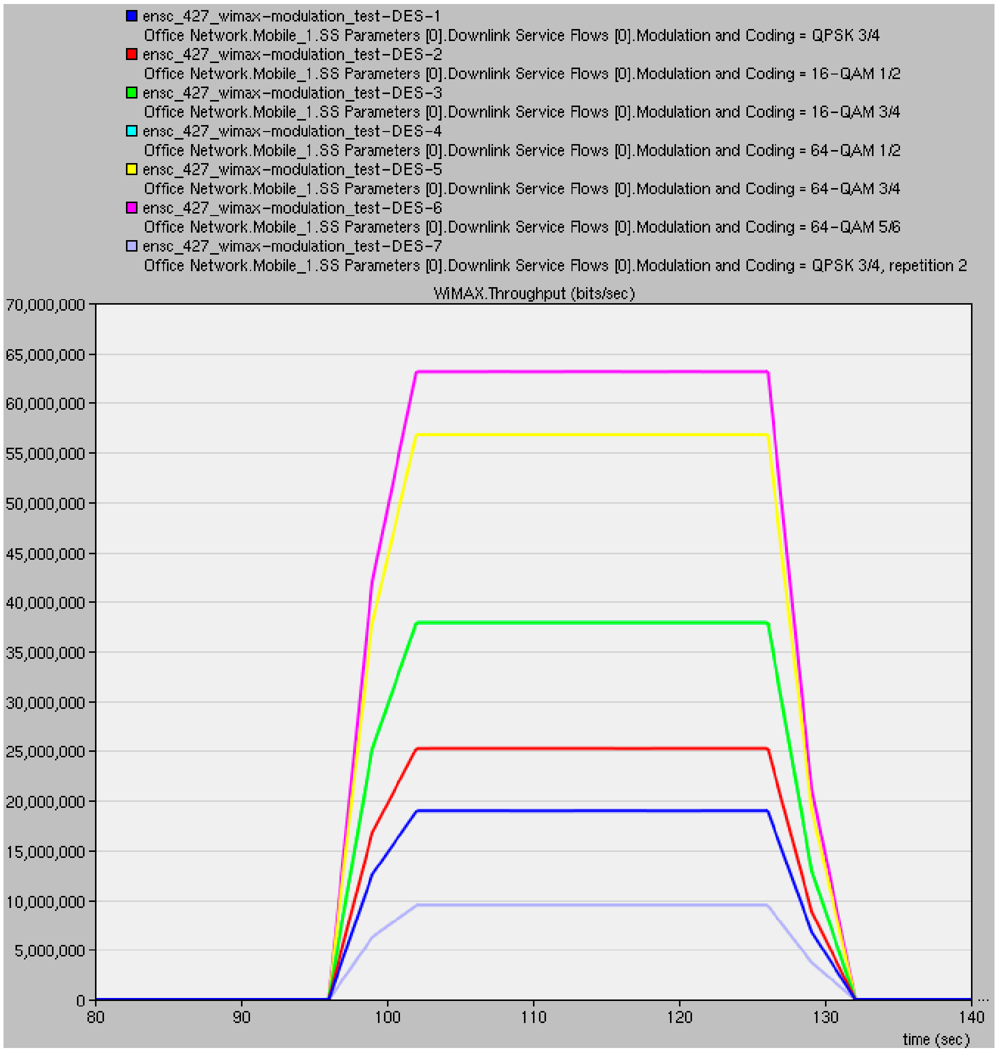


Figure 2: Modulation Schemes

In Subscriber Station configuration we enabled Automatic Repeat reQuest (ARQ) and Hybrid Automatic Repeat reQuest (HARQ). We changed Base Station and Subscriber Station Transmit power to 10 W and 0.5 W respectively to provide ideal conditions for signal transmission.

The screen cap below illustrates our setup for WiMAX network topology.

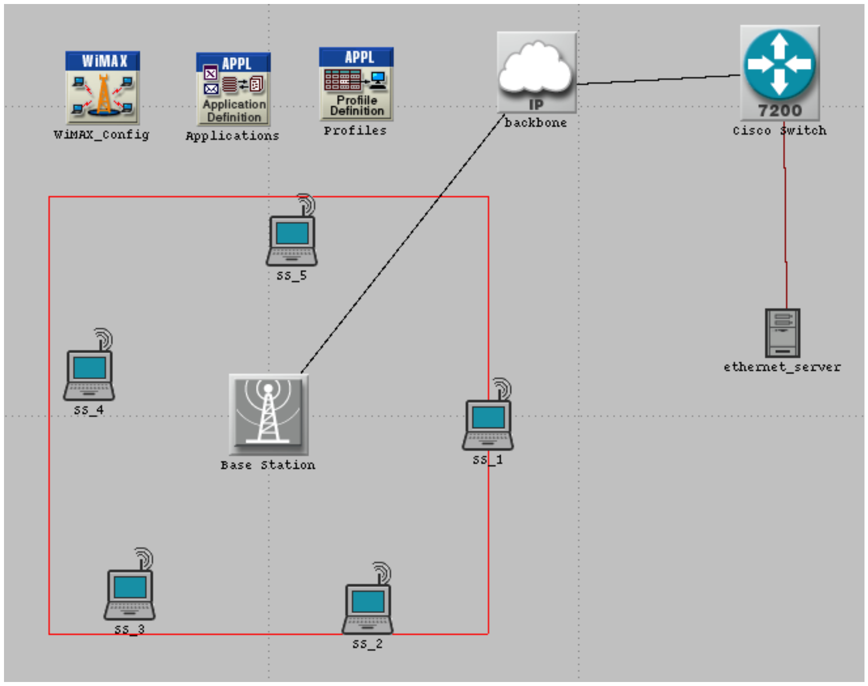


Figure 3: WiMAX Topology

We were unable to use Wireless Network Deployment tool to create LTE network topology; however, since our topology is fairly simple, we manually placed all the required components to produce similar topology as in case for Wi-Fi and WiMAX. Hence, instead of 5 fixed Subscriber Stations we used 5 fixed User Equipments (UE) and instead of the Base Station, we used eNodeB. In addition, LTE requires Evolved Packet Core (EPC) to operate; therefore, it is an additional component in our topology. Please note that in Opnet the EPC is represented as a single object in a topology; however, in reality it consists of many different components which we were not concerned with for our simulation.

As in case with Wi-Fi and WiMAX, we used exactly the same application and profile configuration for LTE. For the efficiency mode we enabled physical simulation and were able to produce good results that correlate to the LTE specifications. Similar to WiMAX Service Class, we specified custom EPS Bearer that we named “Video Bearer”. Video Bearer is set as non-Guaranteed Bitrate (non-GBR) bearer, which is what we require for our simulation to allow for minimum and maximum bit rates. In TFT Traffic filters configuration we assigned all traffic to the Video Bearer.

User Equipment modulation scheme was set to MCS index 28 for our simulation that allows us to produce maximum throughput.

We also changed the eNodeB and User Equipment’s transmit power to 10 W and 0.5 W respectively to remove signal strength as a variable in our simulation.

The screen cap below illustrates our setup for LTE network topology.

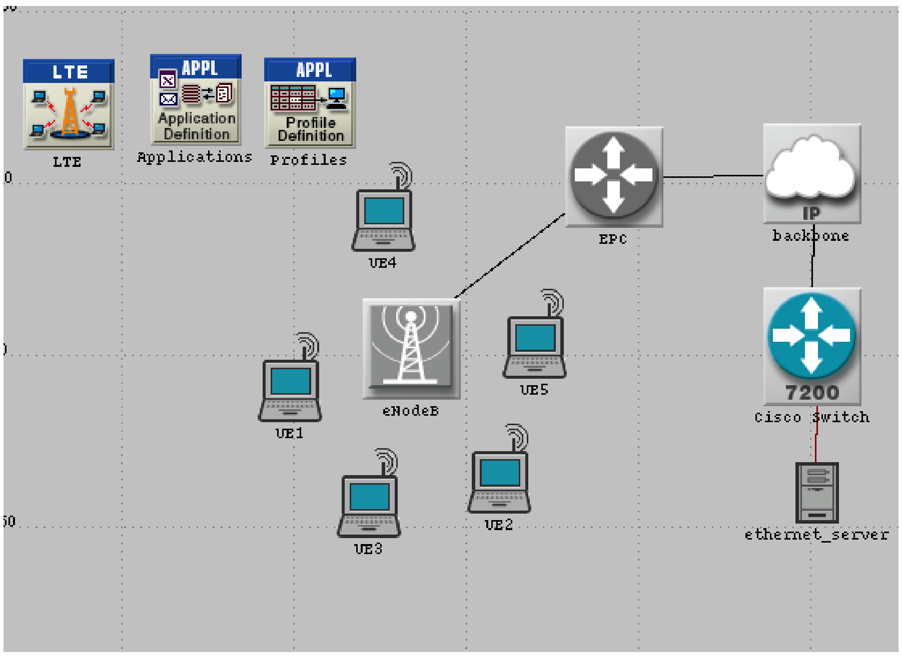
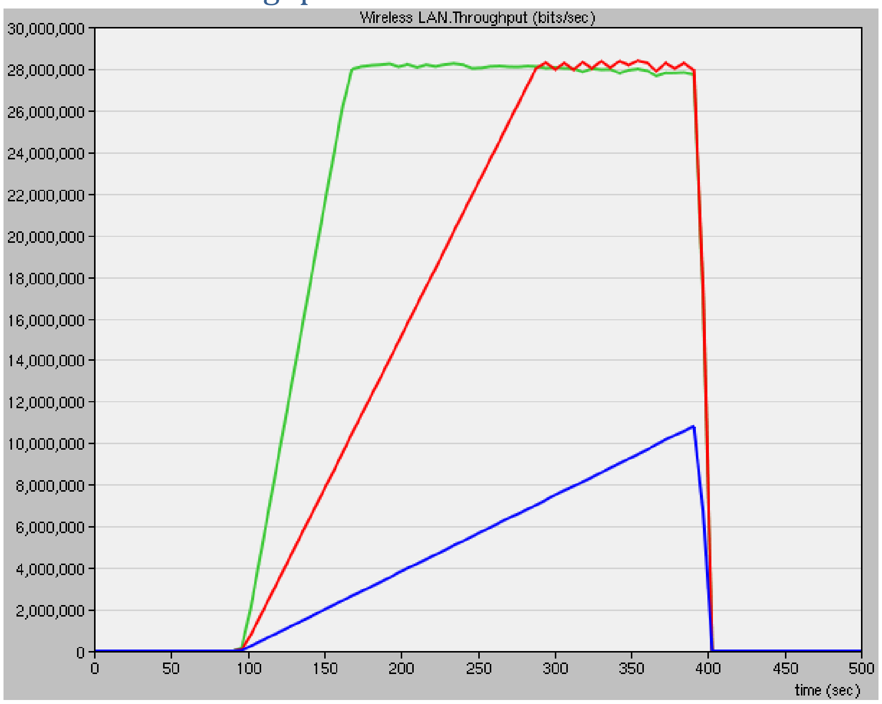


Figure 4: LTE Topology

Technology Specific Results:

The first results we collected were related to pushing the maximum global throughput each technology could support in simulation. These results allow us to determine when the MAC layer of each technology saturates and can no longer scale in increasing traffic. To perform this we employed the use of three linearly increasing video loads being sent to each of our mobile nodes/SS's/UE's.

Wi-Fi Global Throughput:

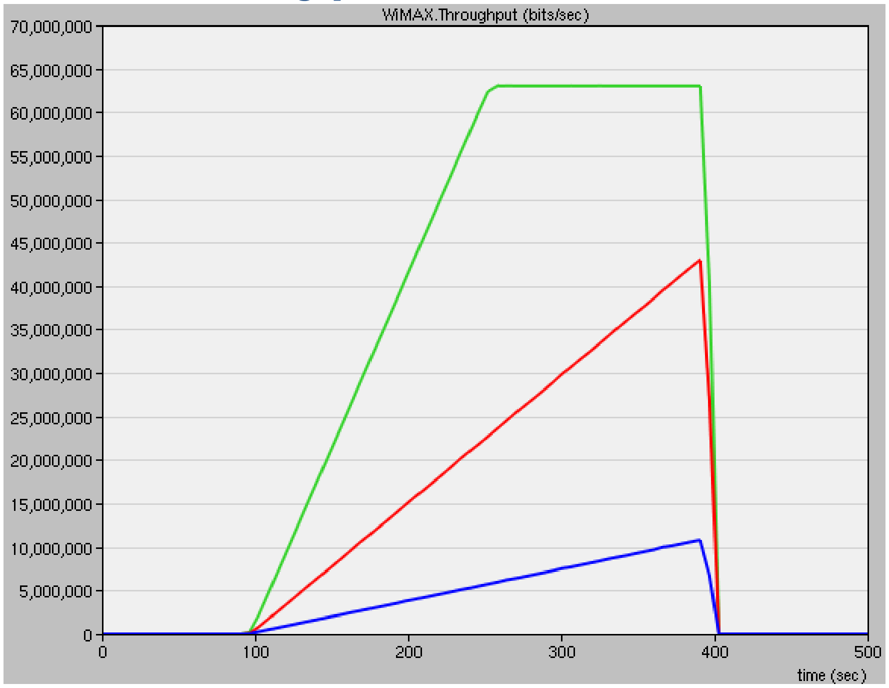


Legend (Per node traffic):
Blue: 0 to 3 Mbit/s Traffic
Red: 0 to 10 Mbit/s Traffic
Green: 0 to 25 Mbit/s Traffic

Figure 5 Wi-Fi Global MAC Throughput

We can see that the 0-3 Mbit traffic profile was unable to saturate the 802.11g specification Wi-Fi. Both the 0-10 Mbit and 0-25 Mbit traffic profiles saturate the Wi-Fi global throughput at about 28 Mbit/s which is lower than the theoretical limit of 54 Mbit/s, however with the overheads simulation this result is expected.

WiMAX Global Throughput:

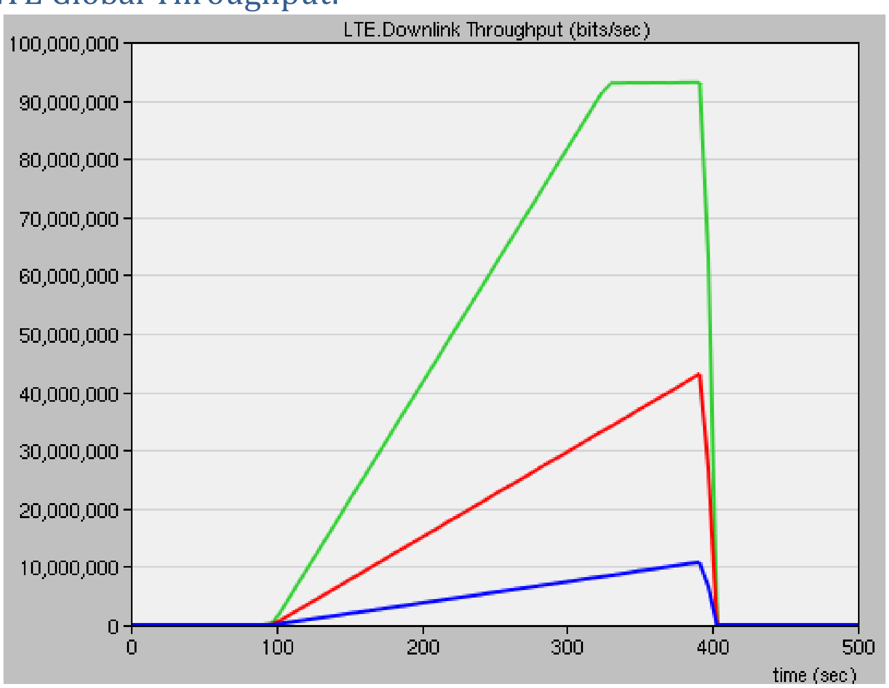


Legend (Per node traffic):
Blue: 0 to 3 Mbit/s Traffic
Red: 0 to 10 Mbit/s Traffic
Green: 0 to 25 Mbit/s Traffic

Figure 6 WiMAX Global MAC Throughput

With WiMAX we see neither the 0-3 Mbit nor the 0-10 Mbit test are able to saturate the WiMAX global throughput. The 0-25 Mbit test however does saturate the WiMAX connected at around 63 Mbit/s which is lower than the theoretical maximum of 83 Mbit/s but within expectations of real world performance. We see significant throughput improvement in WiMAX over 802.11g Wi-Fi.

LTE Global Throughput:



Legend (Per node traffic):
Blue: 0 to 3 Mbit/s Traffic
Red: 0 to 10 Mbit/s Traffic
Green: 0 to 25 Mbit/s Traffic

Figure 7 LTE Global MAC Throughput

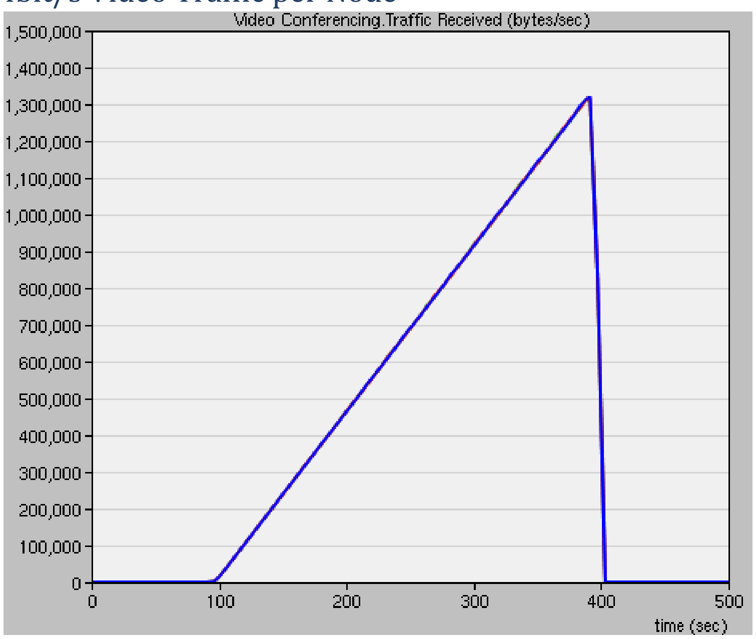
For LTE again we see that it requires the 0-25 Mbit/s traffic profile, our most strenuous test to saturate the LTE downlink throughput. We see LTE reach a maximum throughput of about 93 Mbit/s which is the highest throughput of all the technologies we examined.

Technology Comparison Results

Having examined the maximum throughputs of LTE, WiMAX and Wi-Fi and finding that LTE was the clear winner, we now move onto an examination of four video conferencing statistics. We examined the cross-technology performance of video streaming in terms of the traffic received by the mobile nodes in terms of both bytes/s and packet/s. We also examined the delay and jitter performance of each technology under increasing load.

Video Traffic Received

0-3 Mbit/s Video Traffic per Node

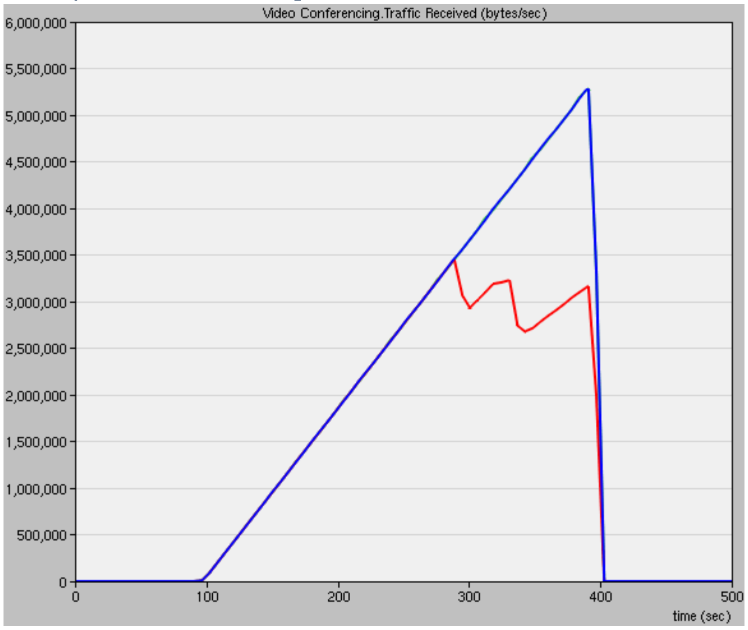


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 8 Global Video Traffic Received (3 Mbit/s)

In terms of traffic received for the low stress 0-3 Mbit/s traffic profile we see identical performance between the three technologies. LTE, Wi-Fi and WiMAX all share the ideal results with no loss and a maximum of just over 1.3 MByte/s.

0-10 Mbit/s Video Traffic per Node

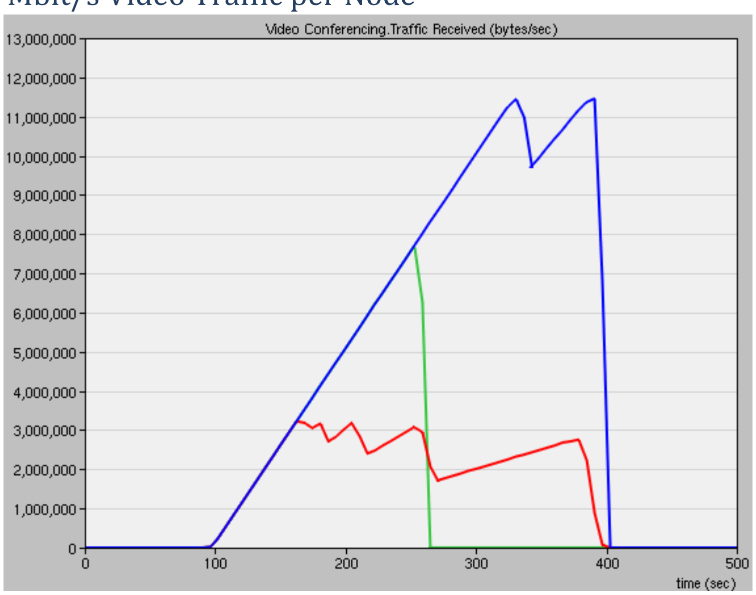


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 9 Global Video Traffic (10 Mbit/s)

In the 0-10 Mbit/s traffic profile we again see identical ideal results from both LTE and WiMAX, however, 802.11g Wi-Fi reaches a maximum of 3.5 MByte/s before video data loss starts to occur. The failure of Wi-Fi makes sense at this global data rate because of the maximum throughput we saw for Wi-Fi was 28 Mbit/s.

0-25 Mbit/s Video Traffic per Node



Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

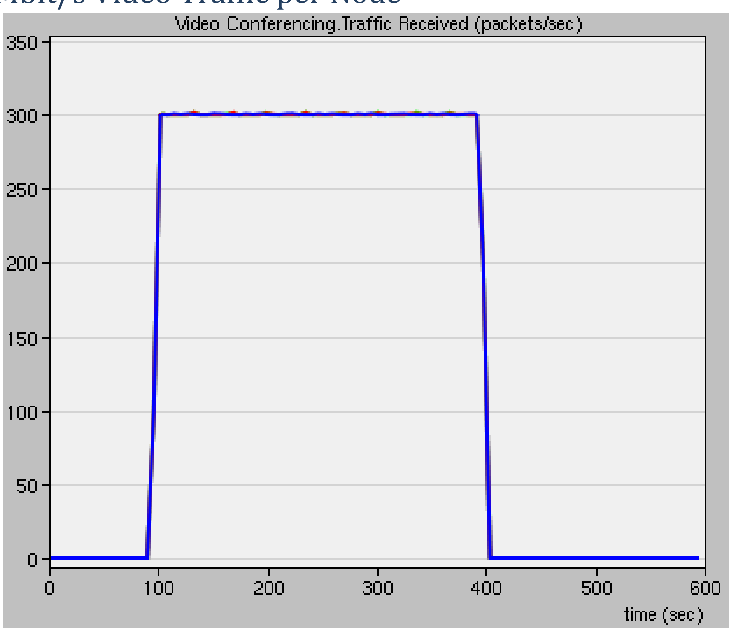
Figure 10 Global Video Traffic Received (25 Mbit/s)

In the high traffic 0-25 Mbit/s traffic profile we see issues emerge with all three technologies as the video traffic attempted to be pushed through the systems exceeds maximum rates. Wi-Fi again maximizes between 3 and 3.5 Mbyte/s of video traffic. WiMAX hits its maximum at about 7.5 Mbyte/s which corresponds to the earlier maximum of about 63 Mbit/s. LTE also reaches its maximum video throughput although it able to push nearly 11.5 Mbyte/s which corresponds with the maximum LTE throughput of about 93 Mbit/s. What is interesting in these results is that while all three technologies reach a maximum rate before dropping data, WiMAX begins to drop all of the video data, while Wi-Fi and LTE continue sending data although it will be incomplete. We think this is due to the QoS settings in WiMAX and would be investigated further in the future.

Video Packets Received (Packet Loss)

We now look again at video traffic received but this time in terms of packets/s instead of bytes/s. We do this so we can more directly see packet loss. The video conferencing application is configured to send 30 packets/s in each direction. We choose a small (10 byte) fixed size for the outgoing frame size which is negligible in the byte/s graphs. Because each mobile nodes sends 30 packets/s and there are five mobile nodes, there are 150 packets received by the server regardless of incoming frame size and performance. The increasing frame size for incoming video data from the server to the mobile nodes accounts for the other 150 packets/s received. Ideal results will show 300 packets/s and if all mobile node received packets are lost the results will show only 150 packets/s representing the packets received by the server.

0-3 Mbit/s Video Traffic per Node

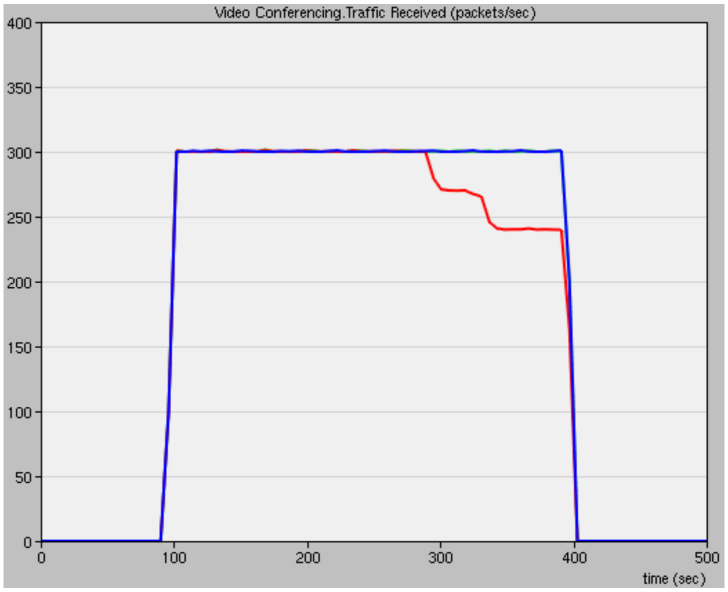


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 11 Global Video Packets Received (3 Mbit/s)

Unsurprising the 0-3 Mbit/s traffic profile shows ideal results for all three technologies with 300 packets received per second at all times video data is sent.

0-10 Mbit/s Video Traffic per Node

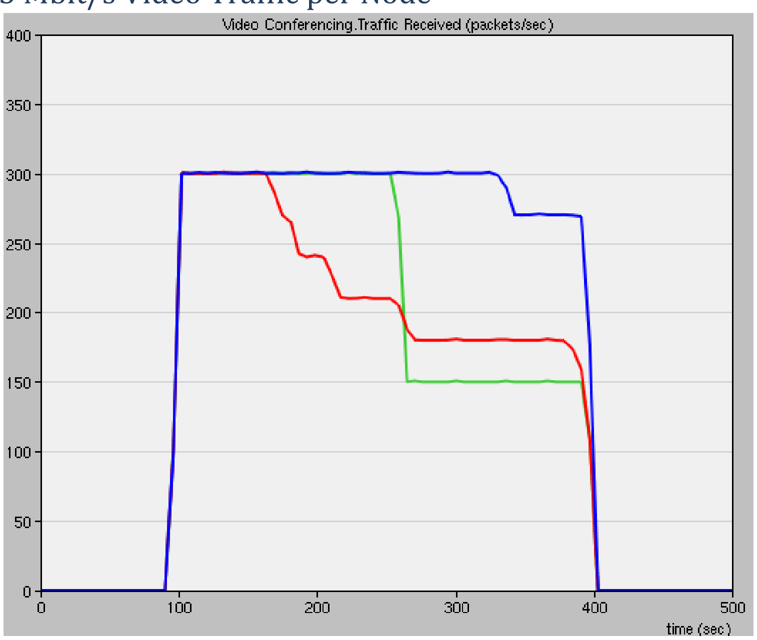


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 12 Global Video Packets Received (10 Mbit/s)

In the 0-10 Mbit/s traffic profile test we see ideal results for LTE and WiMAX at 300 packets/s, however Wi-Fi begins to drop packets, and ultimately drops about 60 of the 150 packets (40% loss) sent to the mobile nodes.

0-25 Mbit/s Video Traffic per Node



Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

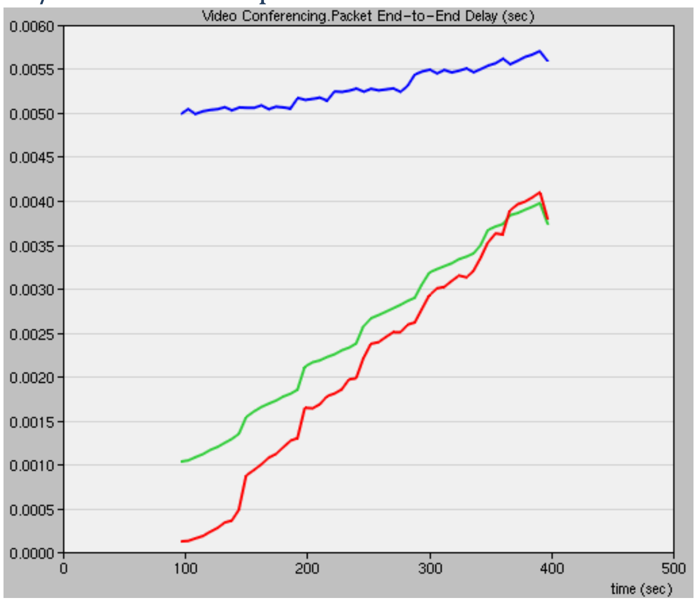
Figure 13 Global Video Packets Received (25 Mbit/s)

For the high traffic 0-25 Mbit/s traffic profile we see packet loss from all three technologies. Wi-Fi begins to drop packets between 150s and 175s and ultimately drops 120 packets/s out of 150 packets/s (80% loss). WiMAX begins to drop all of its traffic sent to the SS's in the range of 250-275s. This corresponds with the nearly 0 bytes/s we see in the video traffic in terms of bytes/s graphs. LTE is able to maintain the full 300 packets/s (150 packets/s per direction) the longest of the three technologies. Around 350s into our simulation LTE starts to drop about 25 packets/s out of 150 packets/s (17% loss).

Video Delay

Video delay is an important metric when watching live or streaming video. It allows parties to communicate correctly in two way communication and helps provide smooth video playback of streaming video.

0-3 Mbit/s Video Traffic per Node

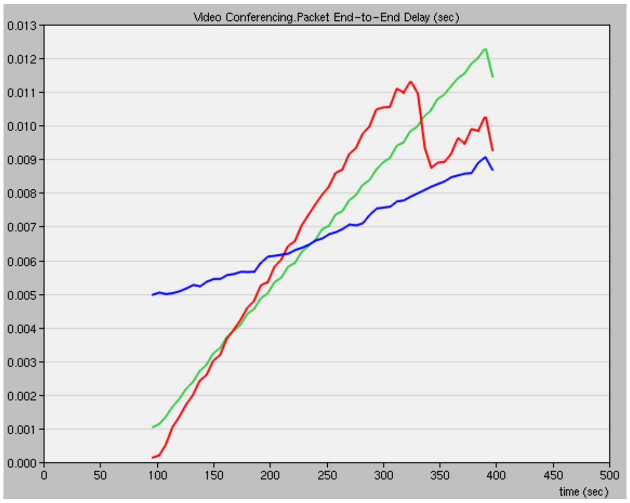


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 14 Global Video Delay (3 Mbit/s)

For the low traffic 0-3 Mbit/s traffic profile we see acceptable delays for all technologies. At low load Wi-Fi and WiMAX have end-to-end delays similar to each other, starting from under 0.5ms for Wi-Fi and 1ms for WiMAX and both reaching about 4ms delay by the end of simulation. LTE's delay under low load is significantly higher than the others at about 5ms at the start and reaching about 5.6ms by the end of simulation. We think this higher initial delay in LTE may be because of the additional modelling of the EPC (evolved packet core) adding more complexity to the LTE model, adding to the delay. Never the less, the increased delay in LTE is still well within reasonable levels for a good quality of experience.

0-10 Mbit/s Video Traffic per Node

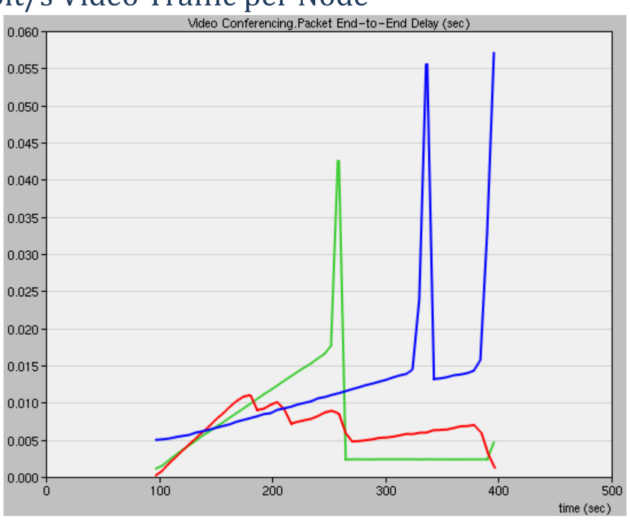


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 15 Global Video Delay (10 Mbit/s)

With the moderate traffic load of the 0-10 Mbit/s traffic profile we see initially the same results as our 0-3 Mbit/s profile. However, as the traffic load continues to increase we see both WiMAX and Wi-Fi surpass the delay of LTE between 200 and 250 seconds. This seems to imply that LTE is able to better withstand higher loads without increasing delay as much as other technologies. Wi-Fi has its maximum delay at just over 11ms before dropping down to 9ms once packet loss starts to occur. WiMAX tops out its delay at just over 12ms when the video traffic is at its maximum. LTE wins this comparison with 9ms of delay without any packet loss.

0-25 Mbit/s Video Traffic per Node



Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

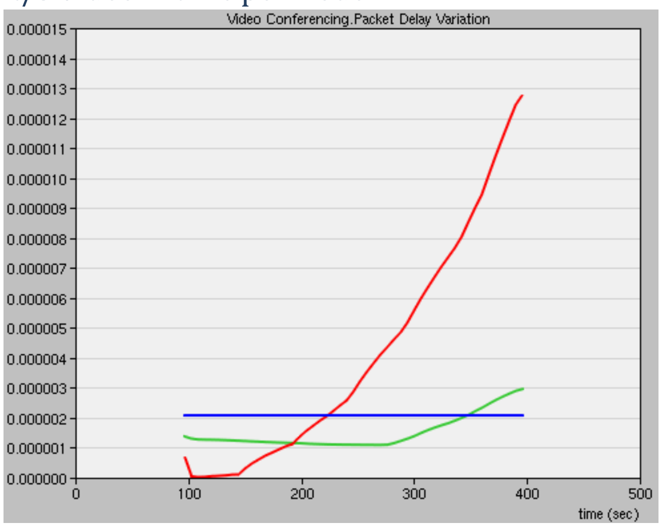
Figure 16 Global Video Delay (25 Mbit/s)

With the high traffic profile of 0-25 Mbit/s we continue to see trends of increasing delay. Wi-Fi continues to max out at 11ms of delay before packet losses allow that delay to fall to between 5 and 10ms. WiMAX has a mostly linear increase in delay up to about 17.5ms where the delay spikes to 42.5ms before falling to 2.5ms when all traffic going towards the SS's is dropped and only the traffic being sent the server remains. LTE also has a linearly increasing delay up to about 15ms where like WiMAX it has a large spike up to about 55ms before it starts dropping packets. This spike repeats itself as the traffic continues to increase and in the future we would like to investigate if the delay would continue to spike periodically as LTE buffers fill up and get dropped over and over.

Video Jitter

Jitter or the variance in delay is also an important quality of experience parameters for many applications including video conferencing and streaming.

0-3 Mbit/s Video Traffic per Node

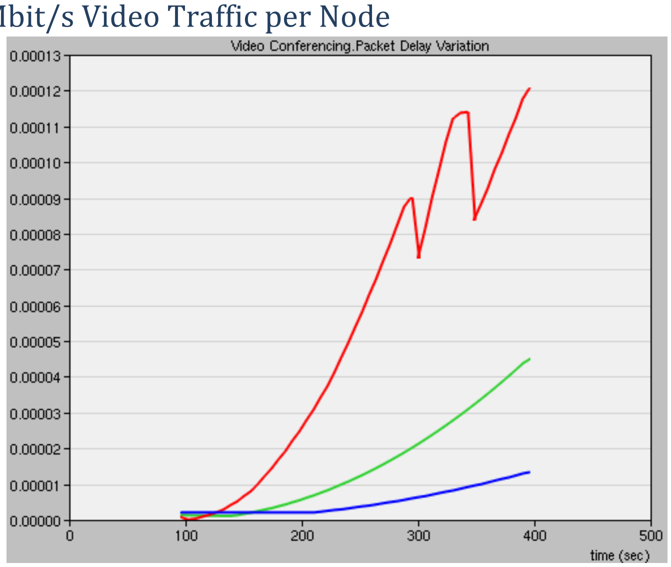


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 17 Global Video Jitter (3 Mbit/s)

For the low traffic 0-3 Mbit/s traffic profile we see very low amounts of jitter across all technologies. For Wi-Fi the amount of jitter increases as the video traffic increases, reaching a maximum of 13µs. WiMAX's jitter also beings to increase once a minimum level of traffic is achieved reaching a maximum 3µs. At this load LTE's jitter performance is unaffected as is constant at just 2µs.

0-10 Mbit/s Video Traffic per Node

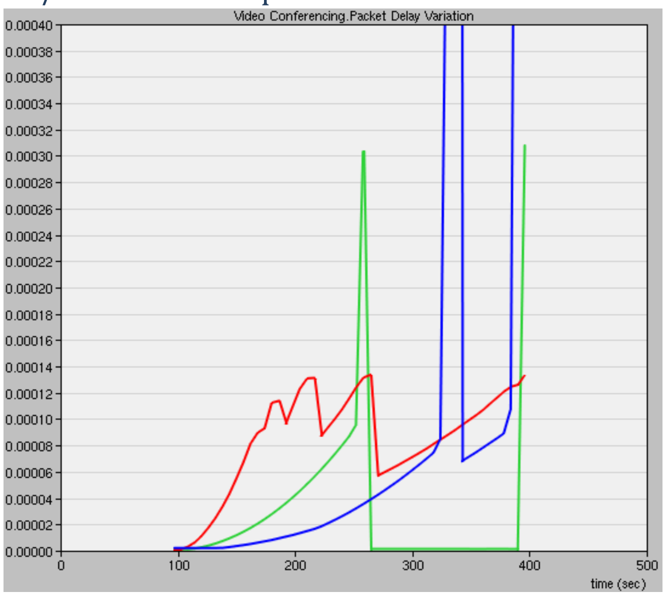


Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 18 Global Video Jitter (10 Mbit/s)

In the medium traffic case using 0-10 Mbit/s traffic we see increases in jitter in all technologies. Wi-Fi continues to suffer from the worst jitter reaching a maximum of 120µs and having the largest slope for increasing jitter as traffic levels increase. WiMAX j.itter increases as traffic increases reaching a maximum of 45µs. LTE again has the lowest jitter which now is impacted by the higher traffic loads. LTE has a maximum jitter of 12µs. All of these values for jitter are acceptable should not greatly impact quality of experience for video streaming.

0-25 Mbit/s Video Traffic per Node



Legend:
Blue: LTE
Red: Wi-Fi
Green: WiMAX

Figure 19 Global Video Jitter (25 Mbit/s)

In our final test we examine jitter performance of the three technologies using our high traffic 0-25Mbit/s traffic profile. We see the maximum jitter for Wi-Fi at about 150µs, however the value is unstable and is affected by the packet loss experienced at these traffic levels. For WiMAX we see a steady increase in jitter to about 100µs before a large spike to 300µs followed by nearly zero jitter. This is explained by the total packet loss WiMAX SS's experience under this load. LTE again has the best stable jitter performance with a steady increase to about 80µs where it then peaks to values above 800µs (off the graph presented) before recovering to its pre-spike values. Like the delay and traffic received, there appears to be periodic thrashing as LTE attempts to handle the excessive traffic load.

Conclusion

We have demonstrated that LTE surpasses WiMAX and Wi-Fi in the following performance characteristics:

- Maximum supported throughput on the DL: up to 93 Mbit/s while WiMAX was only 63 Mbit/s and Wi-FI only 28 Mbit/s.
- Spectrum efficiency: LTE provides the highest data rates of the three technologies while they all utilize 20MHz channel bandwidth, therefor LTE has the highest spectrum efficiency.
- Delay performance: LTE had the lowest delays for high traffic rates and smaller overall increase in delay for a given increase in the load.
- Jitter: lower and more predictable jitter across various data rates.

Based on the above, we confirm our claim that LTE is superior to the reviewed rival technologies in areas such as throughput (data rate), spectrum efficiency, and quality of experience factors such as delay and jitter. 4G LTE provides a new simpler architecture for mobile devices such as phones and tablets and is the clear winner in the contest of technologies to succeed the earlier 3G UMTS/HSPA+ architecture as the mobile communication standard for the world.

References

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[6] C. Y. Yeoh, "Experimental study of 802.11n network," in *The 12th International Conference on Advanced Communication Technology (ICACT)*, 2010.

Appendix

The bash script used to generate increasing frame size for multiple nodes in Opnet is as follows:

```
num_nodes=$1
max_bitrate=$2
duration=$3
file_name=$4

frame_size=1

counter=`expr $duration \* 30`
echo "Counter: $counter"
max_frame_size=`expr  $max_bitrate \*
1000000 / 240`
echo "Max Frame Size: $max_frame_size"
increment=`expr $max_frame_size / $counter`
echo "Increment $increment"
if (( $increment == 0 ))
then
        echo "Max Bit Rate too small for
given duration"
        exit 1
fi


for ((i=0; i < $counter; i++))
do
        for ((j=0; j < $num_nodes; j++))
        do
                echo "$frame_size" | tee -a
$file_name
        done
        frame_size=`expr $frame_size +
$increment`
done
```