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PENETRATION OF LTE-A NETWORKS IN FINLAND AND EAST ASIA

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NELJÄNNEN SUKUPOLVEN LTE-A VERKKOJEN KÄYTTÖÖNOTTO SUOMESSA JA ITÄ-AASIASSA

Tässä opinnäytetyössä käsitellään neljännen sukupolven LTE-mobiiliverkkoja ja tutkii niiden käyttöönottoa ja teknistä tasoa. Lisäksi tutkimuksen kohteena on LTE-A:n mukana tulleet uudet tekniset ominaisuudet, jotka mahdollistavat mm. entistä nopeammat latausnopeudet ja paremman puhelulaadun.

Opinnäytetyön tarkoituksena on saada kokonaiskuva siitä, miten laajalti LTE-A:n käyttöönotto on edennyt niin Suomessa, kuin Etelä-Aasian väkirikkaissa ja moderneissa Japanissa ja Etelä-Koreassa.

Tuloksista ilmenee yksityiskohtaisesti kaikkien kolmen maan kolmen suurimman operaattorin käyttämät verkkojen taajuudet, Carrier Aggregationin käyttämät kaistakonfiguraatiot, taajuuden määrät, huippunopeudet ja myös mahdollisuuksien mukaan LTE-verkon käyttäjien määrä. Lisäksi tuloksissa vertaillaan operaattorien ja maiden välisiä keskinopeuksia ja verkon kattavuutta ja näin ollen pyritään saamaan mahdollisimman kokonainen kuva jokaisen maan LTE tarjonnasta ja mahdollisista LTE:hen liittyvistä testeistä ja erikoisominaisuuksista operaattoritasolla.

Tutkimuksen tuloksista selviää tämänhetkinen tilanne kaikissa kolmessa maassa, sekä vertailua käyttäjämääristä, verkon peitosta ja keskimääräisistä nopeuksista. Vaikka Suomessa ollaankin jääty teknisesti jonkin verran Aasian tahdista, niin käyttäjien vähyys ja verkkojen hyvä laatu takaa suomalaisille operaattoreille hyvät nopeudet. Korea pärjää myös hyvin verkkojensa nopeudessa ja etenkin peitossa. Tutkimusten yllättäjä oli Japani, joka teknisestä etumatkasta ja verkon peitosta huolimatta jäi huomattavasti nopeuksissaan Suomen ja Korean jalkoihin.

ASIASANAT:

LTE, LTE-A, Long Term Evolution, verkko, mobiiliverkko, operaattori, Carrier Aggregation, VoLTE

BACHELOR´S THESIS | ABSTRACT

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PENETRATION OF LTE-A NETWORKS IN FINLAND AND EAST ASIA

This thesis focuses on the 4th generation LTE-A mobile networks and examines their adoption and technical features. In particular, it focuses on the new technical features of LTE-A that enable higher data rates for mobile data and better call quality.

The purpose of this thesis is to analyze the rollout of LTE-A both in Finland and the populous and modern countries of Japan and Korea in East Asia.

The results show comprehensively the bands, frequencies, spectrum, configurations used by Carrier Aggregation, maximum speeds offered, and where possible also the number of subscribers in the LTE networks of all three major carriers in all three countries. In addition, the results of the carriers and countries are compared with each other in terms of average speed, network coverage, subscriber amount, and other data points. This comparison aims to provide as comprehensive picture as possible about the state of LTE in each of the countries, the services each country offers to consumers, and the possible trials that they are conducting to enhance the end-user experience.

The results also provide comparisons of network coverage and speeds. While Finnish carriers have not been able to keep up with the technology race like their Asian rivals, they can still keep up with the average speeds offered by them due to less network congestion and lower LTE penetration level. Finland actually has the best average DL speed of the researched countries. Korea comes in as a close second due to their technical prowess. The great surprise was Japan’s lackluster performance. Although Japanese technology is advanced, frequencies in Japan are more limited and a high penetration rate and a massive subscriber base render the networks congested and slow in comparison.

KEYWORDS:

LTE, LTE-A, Long Term Evolution, Wireless networks, Carrier, Carrier Aggregation, VoLTE

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LIST OF ABBREVIATIONS

Abbreviation	Explanation of abbreviation (source)
LTE	Long Term Evolution (LTE for UMTS – Evolution to LTE-Advanced, Written by Harri Holma, Antti Toskala)
LTE-A	Long Term Evolution Advanced,
WiMAX	Wireless Interoperability for Microwave Access, A competing wireless technology for LTE
MIMO	Multiple Input Multiple Output, spatial multiplexing antennas
eNodeB	The base station used for LTE(-A) transmissions and control
UE	User Equipment, can be a mobile phone or a Mi-Fi etc.
Tx	Transmitter
Rx	Receiver
TDD	Time Division Duplexing, Single user is given a certain time to access the network, separate time is given for down- and uplinks, but the frequency used is same for both links
FDD	Frequency Division Duplex, in this duplexing the downlink and uplink are both given different dedicated frequencies
3GPP	3rd Generation Partnership Project, telecommunication standardization organization
DL	Downlink, traffic that comes form the base station into the UE
UL	Uplink, traffic that goes from the UE into the base station

1 INTRODUCTION

Mobile communication technologies are rapidly evolving and coming more accessible and used around the world. While the research and development is already going on for 5G wireless networks but they won't be implemented before 2020, so in the meanwhile 4G networks will be the primary mobile service, which includes for example Long Term Evolution – Advanced (LTE-A, category 6 and up) and the less well known WiMAX release 2 for our daily mobile data usage. While LTE (up to category 5) in itself doesn't fulfill ITU's requirements for 4G, most carriers still market it as 4G, but in reality LTE-A is required to achieve true 4G speeds.

This thesis is focused on LTE-A, and some of its most important new features specifically Carrier aggregation, which enables LTE-A networks to have higher data rates than it's predecessor. Also VoLTE will be included in the thesis, as it has huge potential to change the way that voice calls are made. Another part of the thesis is research into the market penetration of LTE-A networks in Finland, Japan and Korea.

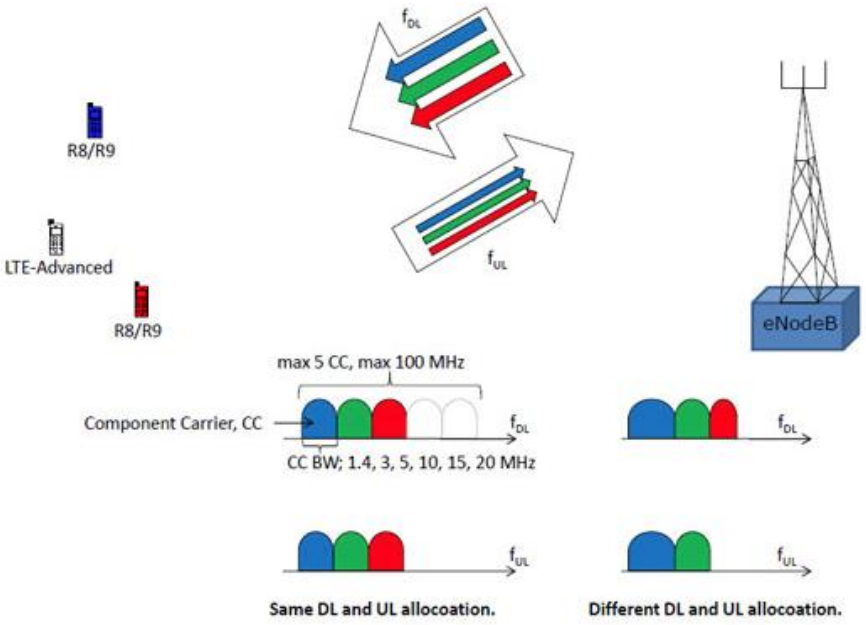
Main focus of the research on different carriers is to find out what technology level (category) they use for their LTE networks, amount of subscribers they have on LTE compared to 3G networks, and the coverage and frequencies of their networks and thus trying to create a picture of where each country is in adopting LTE-A networks.

LTE-Advanced was designed to meet and surpass ITU's requirements for IMT-Advanced 4G networking so the speeds have been increased both in downlink and uplink side. There are few underlying technologies that make this possible these will be discussed in chapter 2.1. The other important new feature is Voice over LTE (VoLTE) which is covered in chapter 2.2

2 OVERVIEW INTO NEW TECHNOLOGIES OF LTE-A

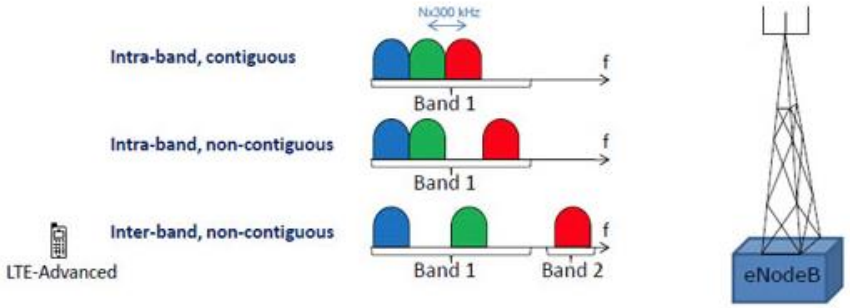
2.1 Carrier Aggregation (CA)

The easiest way to increase the data throughput in mobile environment is to increase the amount of bandwidth that is given to a client. CA takes multiple slots of bandwidth from carrier's frequency and distributes the download load to all of them equally, it allows denominations of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of 5 simultaneous streams and the maximum simultaneous bandwidth of 100 MHz. (Picture 1)



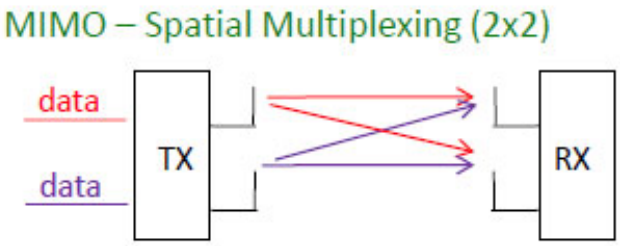
Picture 1. Explanation of Carrier Aggregation Component Carriers. (3PGG) "Carrier Aggregation – FDD The R10 UE can be allocated resources DL and UL on up to five Component Carriers (CC). The R8/R9 UEs can be allocated resources on any ONE of the CCs. The CCs can be of different bandwidths." [1].

The frequency can be taken from the same band of bandwidth or it can combine frequencies of 2 different bands, but this requires the UE to have MIMO antennas installed, so it can utilize 2 different bands at the same time.



Picture 2. Carrier Aggregation types explained. (3GPP [1]).

(Picture 2) shows the principles of CA, the intra-band contiguous mode means taking a larger chunk of the frequency at once. In the Intra-band non-contiguous mode the UE is still using one frequency band, but using different chunks of the frequency at the same time. Meanwhile the inter-band, non-contiguous mode uses 2 different bands, for example 800 MHz and 2100 MHz bands at the same time and takes some frequency, currently most commonly 10 or 20 MHz, from both of them. To use inter-band CA, the UE must be equipped with MIMO antennas to facilitate the use of multiple bandwidths at the same time, one antenna will be required for each different bandwidth that's in use.

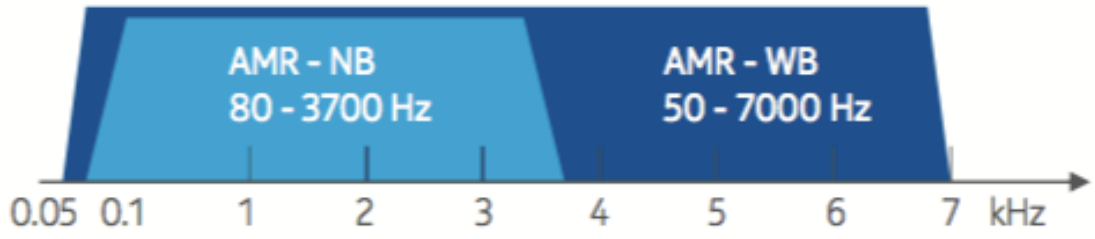


Picture 3. MIMO explanation (3GPP). “Simplified illustration of 2x2 MIMO (Spatial Multiplexing). Two different data streams are transmitted on two TX antennas and received by two RX antennas, using the same frequency and time, separated only by the use of different reference signals.” [1].

Using inter-band CA gives the best reliability, since the network operations can still continue even if one band suddenly loses its connection. LTE-A is can support downlink MIMO antenna (Picture 3) of up to 8x8, which would theoretically allow peak data rates of 600 Mbps with 20 MHz of frequency and 1,2 Gbps with a frequency of 40 MHz, with full 5 aggregated channels and 100 MHz of frequency the speeds can theoretically get to 3Gbps downlink and 1.5 Gbps uplink, these amounts of dedicated frequencies are not possible in real world situations, but nevertheless the real world benefits in speed are considerable. It is also important to note that the eNodeB controls the CA process by gathering information about the UE’s capabilities and status and sets up the CA for that UE, in case of mobility management the CA needs to be set-up each time that the cell is changed, this also allows handoffs to lower category base stations without CA capabilities.

2.2 VoLTE

VoLTE is an IP-based network where all of the voice is handled as data and sent as data packages through the Internet and onto the receiver. Since there is no circuit switched network support both users must have a compatible LTE phone and the carrier must also support VoLTE in their network. VoLTE offers improved call quality over standard circuit switched telephony networks by using AMR-WB codec that offers double voice spectrum compared with legacy CS networks (Picture 4). The call setup time is also decreased in comparison with CS networks, while this is not so important in Finland, it is with countries that have more crowded networks, like those in Korea and Japan. VoLTE is also efficient for the carrier, it allows 2 times more calls per MHz compared to 3G HSPA network and over 5 times more calls per MHz than legacy 2G GSM CS networks. [2] Other added features are switching to a video call on the fly, Internet access during the call and other connected services called Rich Communication Services, that cannot be done using circuit switched networks. In addition VoLTE consumes less battery power compared with standard IP telephony services like Skype, or legacy 3G and 2G calls, which is important on a mobile environment. [2][3]



Picture 4. VoLTE wideband AMR codec bandwidth compared with legacy narrowband codec used in previous CS networks (NSN [2]).

The main drawback of VoLTE is that it’s carrier specific, and currently the co-operation between carriers is minimal, which makes VoLTE quite unreliable for everyday communications, since the receiver needs to also have LTE UE and needs to be on the same carrier’s network.

It will still take some time before VoLTE really becomes mainstream, since these issues need to be addressed first. Another issue is billing, since all of the voice information is now carried as data through the network and most subscribers have data included on their packages now, how do carriers justify separate billing for VoLTE calls when data is included.

3 RESEARCH ON THE PENETRATION OF LTE-A NETWORKS

In this section I will cover each of the countries and carriers independently.

For my research I have chosen three major carriers in each country. These carriers that I have chosen cover for the majority of subscribers in their respected countries

For Finland I have chosen Elisa, TeliaSonera and DNA. These 3 carriers count for 99% of all mobile subscriptions in Finland. Elisa's share is 40%, TeliaSonera's share is 35%, and DNA's share is 24%. [4]

Finland used to be the world leader when it came to mobile technologies. Finland had the first commercial 3G network, and even the first public mobile phone call was made in Finland. So with this entire heritage I wanted to know what's the current state of mobile networks in Finland, has Finland stayed in the lead, or has it fallen behind.

For Korea I have chosen SKT, KT Olleh, and LG U+. For Korea the story is similar, the three big carriers have the market to themselves with the shares being SKT around 47% share, KT Olleh 28% share, and LG U+ 25% share of the customers. [5]

Korea has done remarkably well in pioneering LTE technologies and being in the forefront when it comes to adopting new versions of the technology and they are constantly working with equipment manufacturers on improving the speeds and the capacities of the networks.

For Japan I also chose the three major telcos who have their own networks. Recently there has been an influx of subsidiaries and smaller companies like large electronics store chains, and even Sony getting into the mobile business, but all of these rent the network from one of the three big networks and they will not be covered in this research. The carriers covered are NTT DoCoMo with

40,8% share, SoftBank with 30,3% share, and KDDI group with market share of 28,9%.

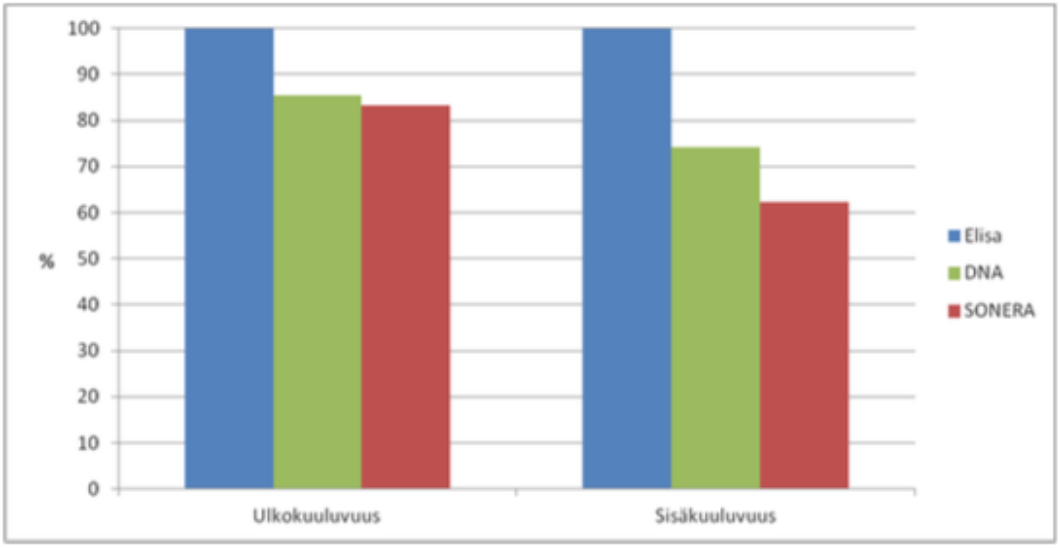
Japan has also been very active in developing LTE, it was NTT DoCoMo that first introduced the concept that would become global LTE standard in 2004.

Of the Japanese carriers SoftBank has somewhat different strategy than it's competitors. SoftBank has aggressively acquired other carriers including Vodafone Japan, eMobile, WillCom etc. It has also acquired more than 90% of the US carrier Sprint. In addition they're also expanding to other fields and have acquired Japanese mobile gaming company GungHo, and Finnish mobile gaming company Supercell. They have also acquired a wireless network planning company called Wireless City Planning.

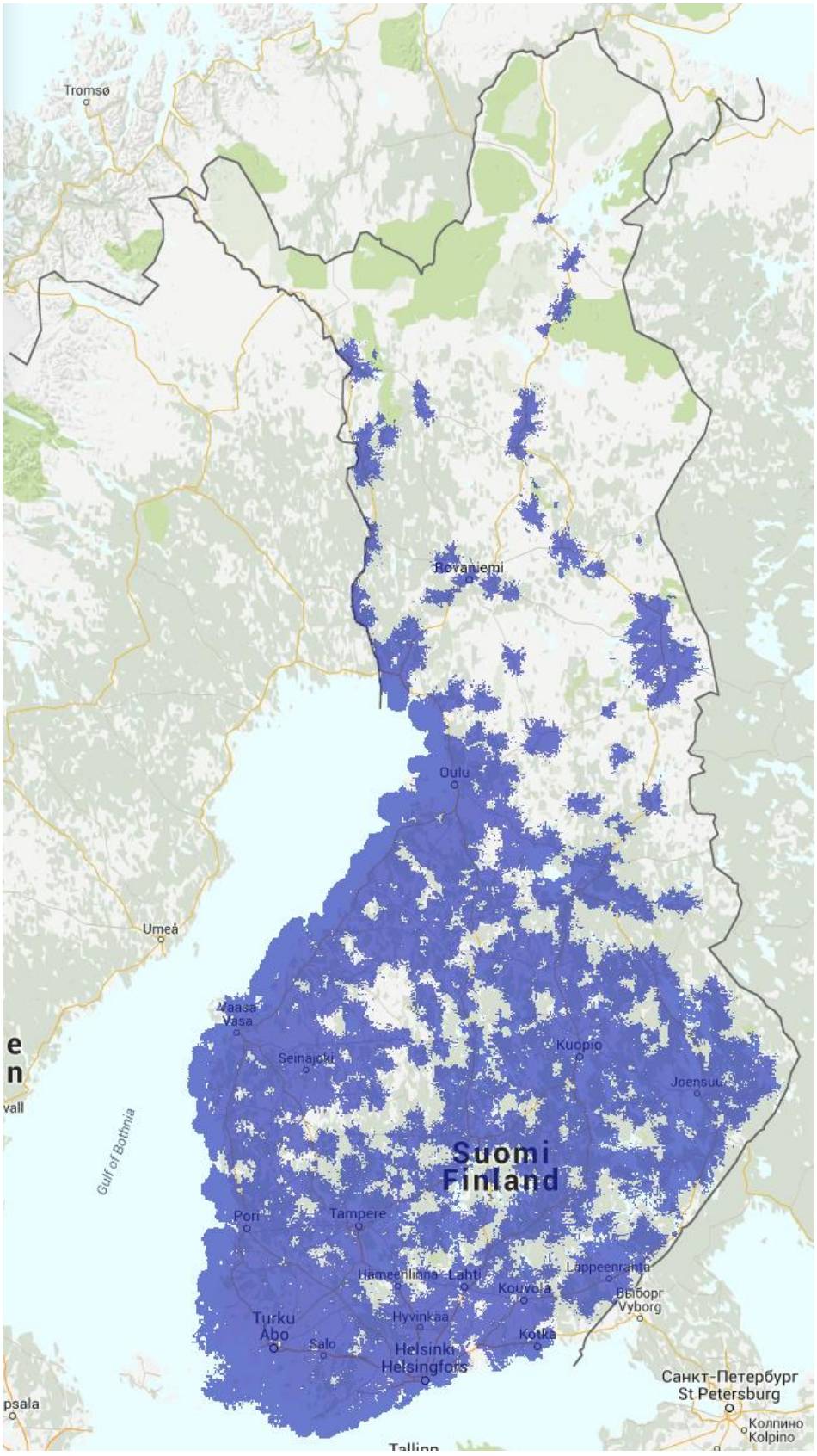
3.1 Finland

3.1.1 Elisa

The Finnish telecommunications carrier Elisa OYJ is marketing itself as having the widest LTE network in Finland (Graph 1, Picture 5), their LTE network covers majority of the population in Finland, around 96%.



Graph 1. A graph of the LTE network coverage in Finland by carrier. The left graph shows outdoor coverage and right graph shows indoor coverage (ECE [6]).



Picture 5. Elisa's LTE network coverage (Elisa [7]).

Elisa has LTE networks operating at the following LTE bands (Table 1)

Band	Frequency range	Amount of frequency	Carrier Aggregation	Aggregated frequency
20	800 MHz	10 MHz		
3	1800 MHz	20 MHz	CA_3A_7A	40MHz
7	2600 MHz	20MHz	CA_3A_7A	40MHz

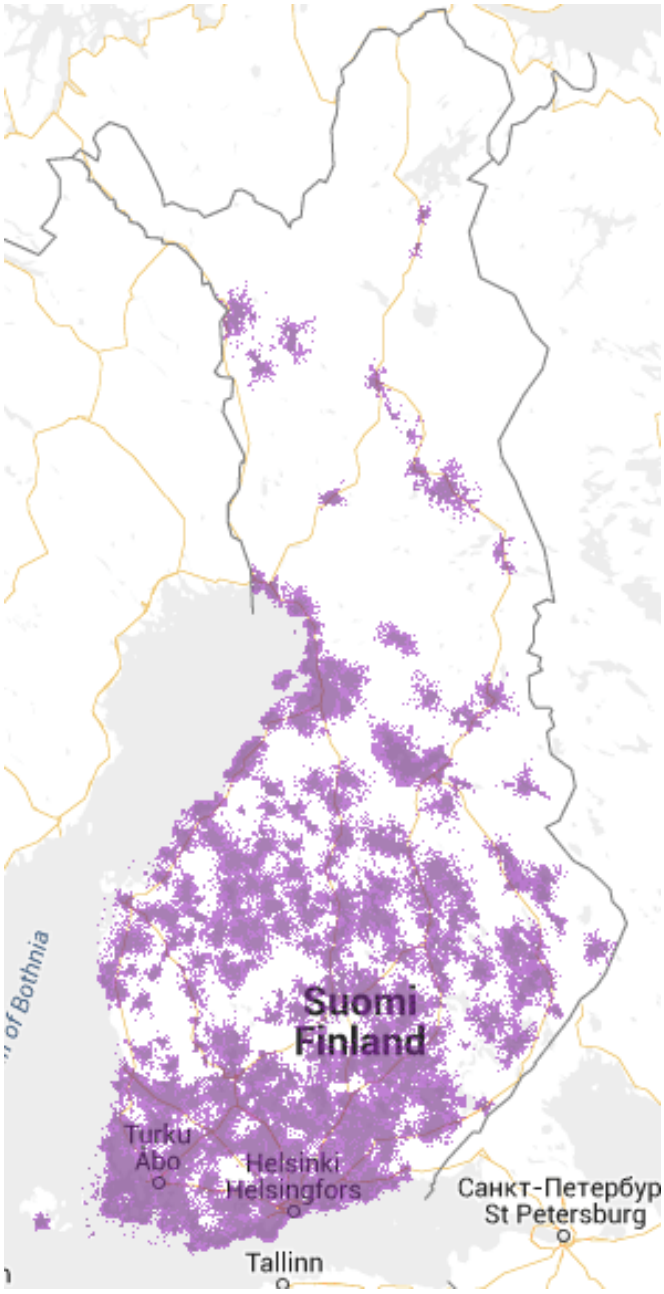
Table 1. Bands, frequencies, and Carrier Aggregation used by Elisa.

All of the bands use FDD duplexing to allocate the frequency to users. Elisa is also planning on introducing Cat 6 LTE-A networks from summer 2015 and are currently trialing the system at select base stations in 12 major Finnish cities, and they're already selling subscriptions for LTE-A. In their trials Elisa combined 20 MHz frequency of band 3 and 20 MHz of band 7 in inter-band CA scheme CA_3A_7A and achieved 300 Mbps speeds [8], however speeds for end users are expected to be slower than this.

Fastest speeds that Elisa offers on their LTE network currently is 100 Mbps, but the 300 Mbps LTE-A network is expanding rapidly to allow access for more customers, and already covers 12 major Finnish cities, which is more than it's competitors are offering at this time. Currently Elisa has no active plans on implementing VoLTE technology in their network. Elisa uses Nokia Solutions Networks' Flexi Multiradio 10 eNodeB base stations, which are fully compatible with LTE-A as well as LTE, and also legacy 2G and 3G networks. [9, 10]

3.1.2 TeliaSonera

TeliaSonera's LTE network is not quite as large as Elisa's (Picture 6). Their LTE coverage is about 75% of the population of Finland, to remedy this Sonera and DNA signed a cooperation agreement on sharing their network in sparsely populated northern and eastern parts of Finland to offer better coverage in these areas. [11]



Picture 6. Sonera's LTE network coverage (Sonera [12]).

Sonera uses the following LTE bands (Table 2)

Band	Frequency range	Amount of frequency
20	800 MHz	10 MHz
3	1800 MHz	20 MHz
7	2600 MHz	20 MHz

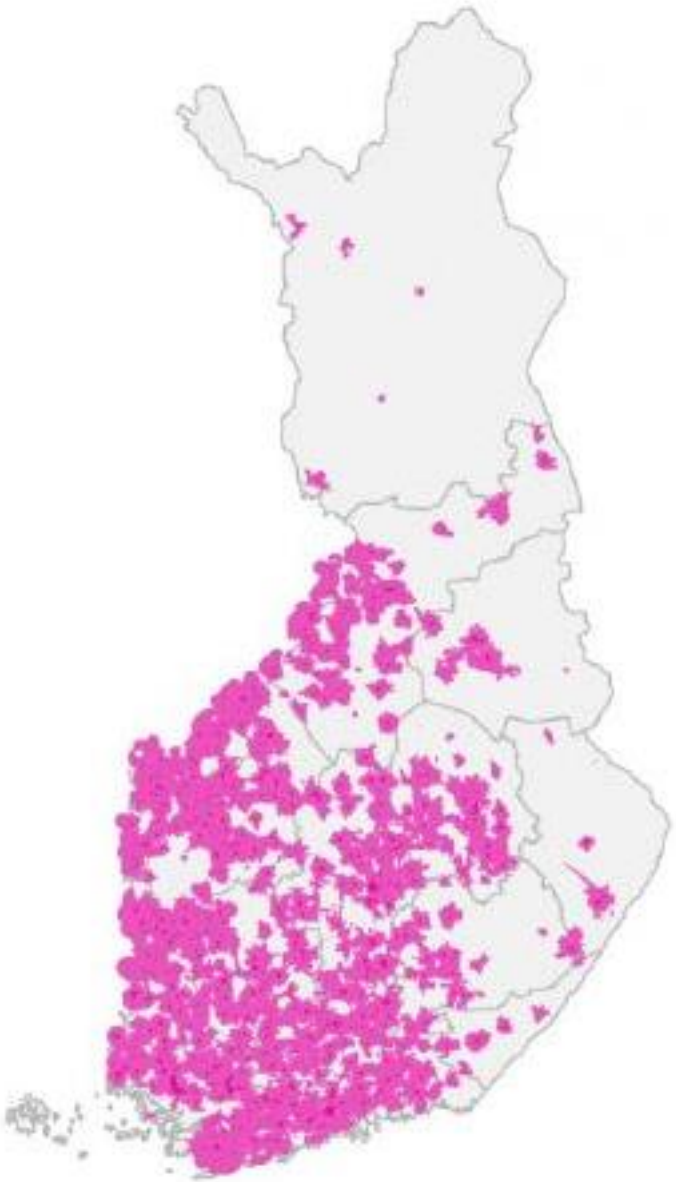
Table 2. Bands and frequencies used by TeliaSonera Finland.

Sonera has also trialed Cat 6 LTE-A in some of their eNodeB's in Helsinki region with inter-band CA scheme CA_3A_7A, which allows maximum of 40 MHz to be utilized from two different bands, in this case bands 3 and 7. This allows maximum speed of 300 Mbps to be achieved. Sonera launched their trial Cat 6 network in December of 2014, but sells subscriptions for it only for their corporate customers, not to the general public, this combined with the lack of the eNodeB's makes Sonera's network speed effectively 150 Mbps. Sonera, like Elisa is also using NSN's Flexi Multiradio 10's for their LTE-A network.[13]

It is worth noting that out of the major operators in Finland Sonera is the only one that has limited data usage on their plans before downgrading the speed to 2G, this is very similar to data plans abroad in different parts of the world, like Korea and Japan.

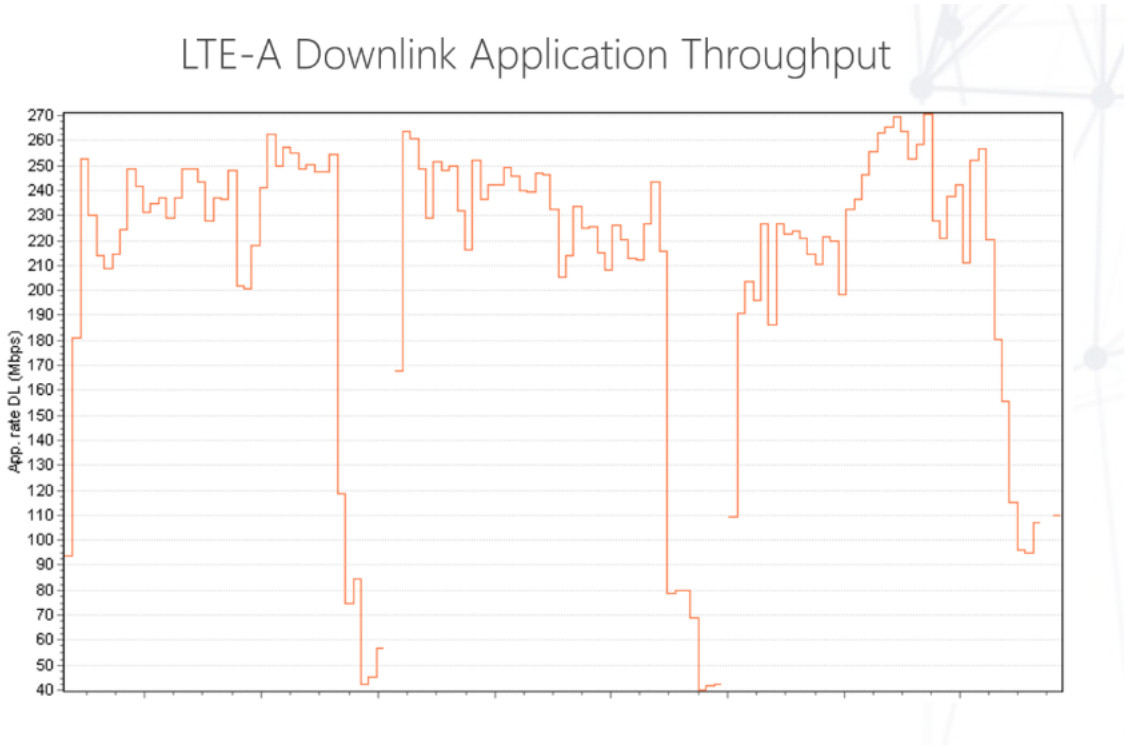
3.1.3 DNA

DNA used to have the poorest LTE coverage in Finland (Picture 7), but with the inclusion of the 800 MHz band and cooperation with TeliaSonera their coverage has improved significantly and now covers nearly 80% of the Finnish population. Their LTE speeds have been tested to have the highest average of the big three carriers in Finland [14]



Picture 7. DNA's LTE network coverage in 2014 (DNA [15]).

DNA is trialing their LTE-A network in select eNodeB's in Helsinki area starting from March 2015, sadly their trials have fallen behind other carriers by peaking at 270 Mbps (Graph 2). DNA currently isn't rolling out LTE-A in other locations.



Graph 2. A graph of DNA'S LTE-A trial speeds (Omnitele [16]).

Band	Frequency range	Amount of frequency
20	800 MHz	10 MHz
3	1800 MHz	20 MHz
7	2600 MHz	20 MHz

Table 3. Bands and frequencies used by DNA.

DNA is using LTE bands 3, 7, and 20 (Table 3). DNA is also using CA_3A_7A scheme for trial Carrier Aggregated network, combining total of 40 MHz of fre-

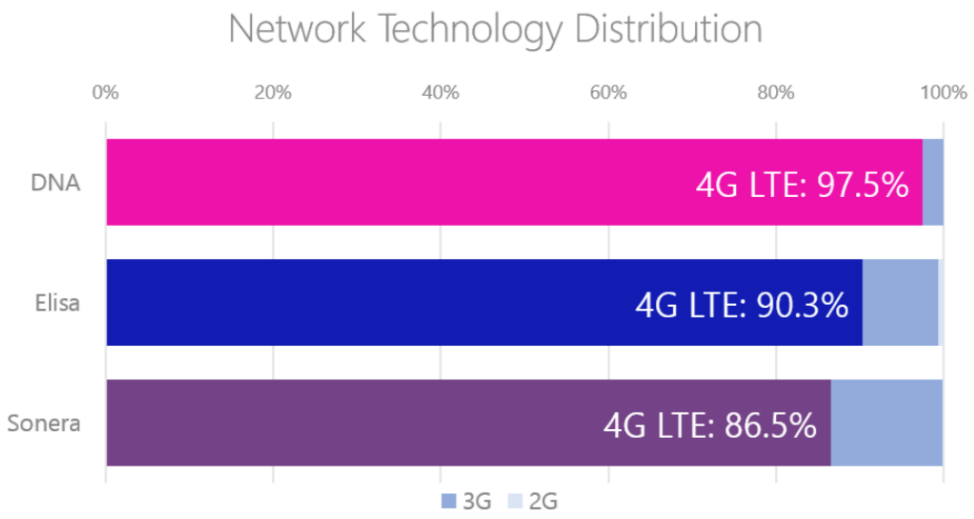
quency to achieve 270 Mbps speeds. DNA has gone with Ericsson as their sole supplier to supply them with their RBS 6000 eNodeB architecture. [17]

3.1.4 Conclusions and summary – Finland

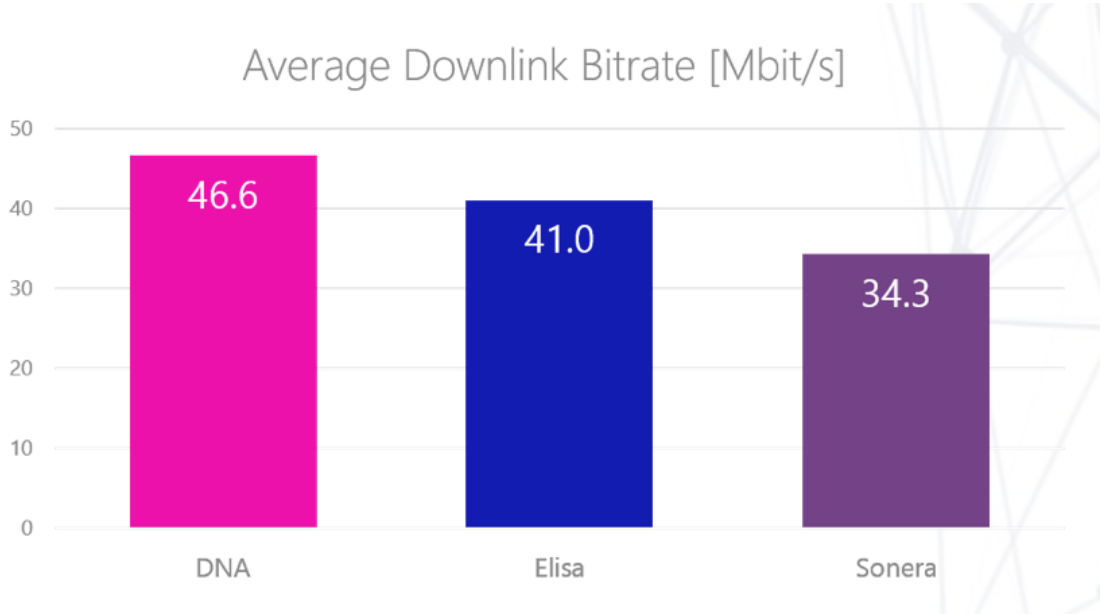
In conclusion about Finland LTE-A has been trialed by all of the major carriers, and is being implemented by Elisa, and should be launching very shortly. Due to Elisa's push the other carriers are bound to follow the trend at some point in near future in order not to fall behind Elisa in terms of speeds offered. But currently the only carrier, who is actively pushing for LTE-A coverage in multiple locations around Finland, is Elisa.

Currently none of the carriers have plans to introduce VoLTE services in Finland, but TeliaSonera in Sweden are already planning on rolling it out so I suspect that it's only a matter of time before VoLTE finds it's way to Sonera's network in Finland as well and after that to the other carriers as well [18].

It seems like LTE has catched-on with the power users in Finland, and it already counts for vast majority of all data usage in Finnish networks, around 90% of all mobile data traffic (Picture 9, 10). But it's still lagging in market penetration and is far from being mainstream like 3G, this is probably due to the pricing of the LTE contracts, the cheapest LTE plans start at 20€/month for 50 Mbps / 25 Mbps connection and can run up to 50€/month for Elisa's Cat 6 LTE-A 300 Mbps plan. While this seems to be acceptable for the power users, it's still too high for the standard user who's just using the connection for browsing and emails etc.



Graph 3. Comparisons of data usage in different Finnish carriers by wireless technology, as we can see LTE already counts for around 90% of all data traffic in total (Omnitele [14]).



Graph 4. Tested average LTE downlink speeds in Finland under optimal conditions (Omnitele [14]).

With these graphs in mind we can conclude that the market penetration of LTE in Finland is currently only about 25% [5]. However these 25% of subscribers consume 90% of all the mobile data in Finland (Graph 3), which proves us that

people, who use mobile data for internet sharing, streaming, downloading large files, and other heavy tasks have migrated to using LTE (Graph 3, 4).

DNA is the only carrier who relies on Ericsson eNodeB base stations instead of NSN’s equipment. This might explain the performance differences that we can see both in their LTE networks and LTE-A trial network.

3.2 South Korea

3.2.1 SK Telecom

SK Telecom has been a pioneer in rolling out LTE-A networks, they launched the first commercial LTE-A network in September 2013 with it's rivals LG U+ and KT, allowing speeds of 150 Mbps, and then again in mid 2014 when they were the first to commercially launch Cat 6 service for the Korean public on 19th of June 2014. However SKT gained access to band 1 in January 2015 allowing full 300 Mbps service to start. SKT also launched VoLTE services in August 2012, being one of the first carriers in the world to do so.

SKT has operated LTE network since 2011 and started LTE-A operations in late 2013. SKT operates on LTE bands 5, 3, and recently they got access to band 1, SKT uses FDD duplexing for all of their bands. (Table 4)

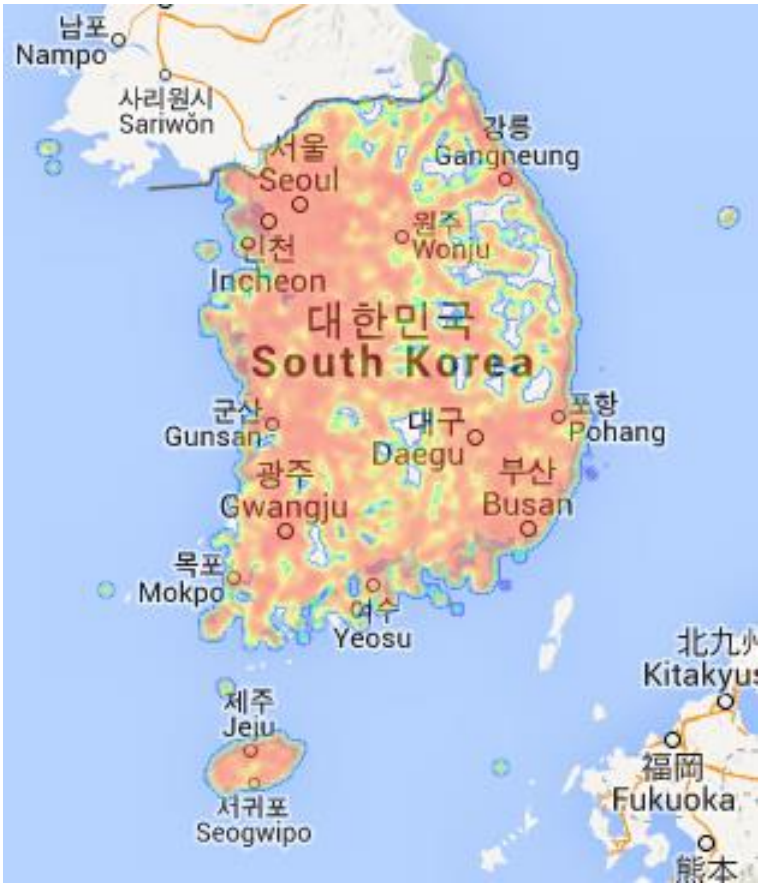
Band	Amount of frequency	Frequency for DL	Frequency for UL	Carrier Aggregation
5 (850 MHz)	10 MHz	874-884 MHz	829-839 MHz	CA_3A_5A, 20-30 MHz (150-225 Mbps)
3 (1800 MHz)	20 MHz	1810-1830 MHz	1715-1735 MHz	CA_1A_3A_5A, 40 MHz (300 Mbps)
1 (2100 MHz)	10 MHz			

Table 4. Bands, frequencies, and Carrier Aggregation used by SKT.

Because of multiple denominations of bandwidth SKT is using multiple different CA schemes to best suit them. For Cat 4 service they use CA scheme CA_3A_5A with 20 MHz of frequency, the same scheme can be used in Cat 6 with frequency of 30 MHz allowing speeds of up to 225 Mbps to be achieved. For newer UE's they can offer CA_1A_3A_5A and utilize the whole spectrum of 40 MHz and offer 300 Mbps speeds[19], this however requires extra MIMO antenna and largely due to this fact Korea has tailored domestic models of their phones from LG, Samsung, and Pantech to facilitates these differences, these

models are also heavily tailored for the specific carrier that sells them. Utilizing the full 40 MHz spectrum is heavily location and network load dependent and requires good network conditions to work.

SKT's LTE network covers over 93% of population of South Korea (Picture 8), and they have also a concept called "3D LTE" which refers to SKT having cell towers on top of mountains, hills, and on subways so that LTE signal is uninterrupted wherever the user might be. The amount of LTE subscribers SKT has is over 15,000,000. [5]



Picture 8. SK Telecom's LTE network coverage (OpenSignal [20]).

3.2.2 KT Olleh

KT has been offering Cat 6 LTE-A services to its customers from June 30th of 2014, so they were actually the last Korean carrier to offer these services. Like SKT they got access to band 26 in early 2015 making their initial offering 225 Mbps LTE-A. KT launched full nationwide VoLTE services in October 2012

Currently KT operates 3 LTE bands, band 3, band 8, and band 26. (Table 5)

Band	Amount of frequency	Frequency for DL	Frequency for UL	Carrier Aggregation
26 (850 MHz)	10 MHz			
8 (900 MHz)	10 MHz	950-960 MHz	905-915 MHz	CA_3A_8A, 30 MHz (225 Mbps)
3 (1800 MHz)	20 MHz	1830-1850 MHz	1735-1755 MHz	CA_3A_8A_26A, 40 MHz (300 Mbps)

Table 5. Bands, frequencies, and Carrier Aggregation used by KT Olleh.

This allows for a 30 MHz carrier aggregation scheme CA_3A_8A with maximum speeds of 225 Mbps to be used. And now with the addition of band 26 KT supports CA_3A_8A_26A for full 40 MHz 300 Mbps Cat 6 speeds.

KT's full Cat 6 support is achieved through tri-band inter-band carrier aggregation. This limits the usability of the whole spectrum since it needs ideal conditions to achieve full speeds that Cat 6 can offer. This is easily hindered by less than optimal signal quality from at least one of the aggregated bands, and network congestion caused by large amount of simultaneous users in large cities and high penetration rate of LTE in Korea.

Picture 9. KT Olleh's LTE network coverage (OpenSignal [20]).

KT’s LTE network covers over 94% of Korea (Picture 9) being the second biggest in terms of LTE subscribers totaling in over 9,000,000 LTE subscribers. [5]

3.2.3 LG U+

Subsidiary of LG Corporation, LG U+ offers full carrier services to its customers.

LG U+ was the second carrier in Korea to introduce LTE-A networks to the market in June 26th 2014.

LG U+ started with all bands required for Cat 6 LTE-A services with full 40 MHz spectrum. Yet initially offered just 30 MHz CA with 225 Mbps performance. More recently LG U+ has started supporting full Cat 6 speed of 300 Mbps

The bands LG U+ uses are band 5, band 1, and band 7. (Table 6)

Band	Amount of frequency	Frequency for DL	Frequency for UL	Carrier Aggregation
5 (850 MHz)	10 MHz	884-894 MHz	839-849 MHz	CA_1A_5A, 20 MHz (150 Mbps)
1 (2100 MHz)	10 MHz	2110-2120 MHz	1930-1940 MHz	CA_1A_5A_7A, 30 MHz (225 MHz)
7 (2600 MHz)	20 MHz	2640-2660 MHz	2520-2540 MHz	CA_1A_5A_7A, 40 MHz (300 Mbps)

Table 6. Bands, frequencies, and Carrier Aggregation used by LG U+.

LG U+'s CA schemes include CA_1A_5A 20 MHz for Cat 4 speeds, CA_5A_7A 30 MHz for 225 Mbps service and finally tri-band CA_1A_5A_7A for full Cat 6 40 MHz 300 Mbps service.

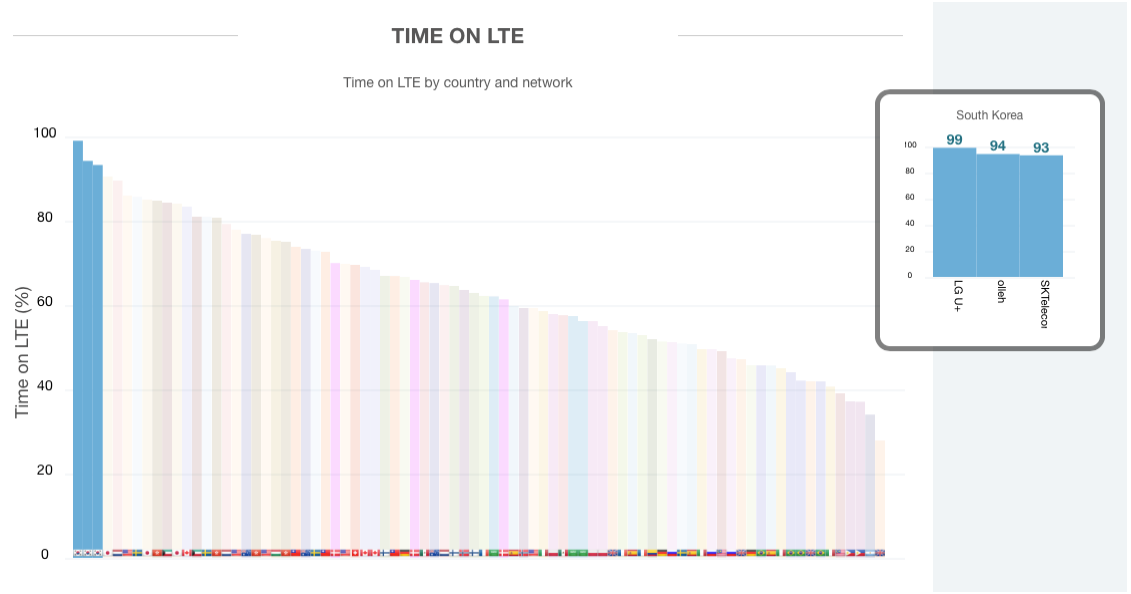
Picture 10. LG U+'s LTE network coverage (OpenSignal [20]).

LG U+ has the best LTE coverage reaching 99% of Koreans nearly everywhere they go (Picture 10). Looking at the subscriber numbers they’re the smallest of the Korean carriers with LTE subscriber base of 8,000,000 [5]

3.2.4 Conclusions and summary – South Korea

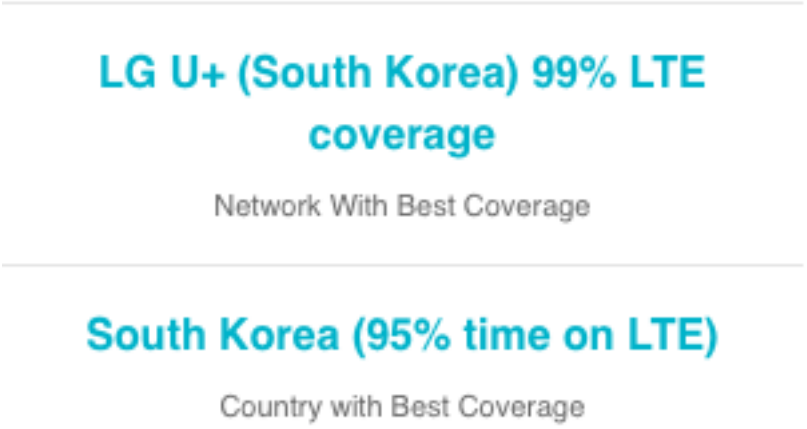
While South Korea is the most advanced of the countries in LTE-A technology, introducing the first commercial nationwide Cat 6 services and are constantly pushing the envelope of what can be done with LTE technology in forms of partnering with NSN, Samsung, and other network equipment and UE manufacturers to perform cross technology tests and debut new technologies and innovations before anyone else. Korea also has the best LTE coverage in the world, which guarantees that virtually all Koreans have access to LTE no matter where they might be (Graph 5), also their LTE subscriber numbers are world's highest with around 70% of subscriber base subscribed into LTE services.

However the non-unified use of different bands by different carriers means that UE's have to be customized for each carrier, and are not cross compatible with each other's CA technologies, also the sheer amount of LTE subscribers, which is already nearly 35,000,000 means that networks are very loaded at all times and this decreases the overall performance for subscribers. And due to their tri-band Cat 6 design it is difficult to achieve maximum speeds even during good network conditions.



Graph 5. This graph shows the average time that a subscriber spends in the coverage area of LTE network, South Korea has best LTE network Coverage in the world with having over 90% coverage for all carriers (OpenSignal [21]).

Korea's LTE coverage is the best in the world (Picture 11) and they have the best LTE penetration rate with roughly 70% of the population already subscribed for it. [5]



Picture 11. Korea has world's best LTE coverage (OpenSignal [21]).

This does mean however that the networks are crowded and end-user experience is not optimal at all times, which leads to lower average speeds for the users, however South Korea is one of the best and countries in the world LTE wise, and definitely the spearhead of the LTE revolution.

Also all Korean carriers have been spearheading the launch of VoLTE services and due to the high LTE penetration in Korea most Koreans are already enjoying high quality VoLTE calling and services.

The price for LTE contracts in Korea depends on the usage, since data is limited on most contracts. Prices start from around 60,000 won (~60 USD) for 5GB data and runs up to as much as 80,000-120,000 won (80-120 USD) depending on the contract period and carrier for unlimited LTE data plans, these also have daily usage cap before carriers significantly downgrade the speed of the connection, so truly unlimited high speed LTE plans don’t exist yet.

Looking to the future NSN and SKT have cooperated in a trial using both FDD and TDD CA at the same time while combining 10 spectrums totaling in 200 MHz of frequency and the result was throughput 3.78Gbps, which would result in streaming of a 5 GB HD movie in just 11 seconds. While speeds like this won’t be feasible in real life using LTE technology due to the amount of bandwidth required, the current maximum being CA of 5 bands and 100 MHz of frequency it does show that combining FDD and TDD duplexing would result in solid results. [22]

3.3 Japan

3.3.1 NTT DoCoMo

NTT DoCoMo was the first carrier to propose the format of in LTE in 2004. Later this proposition was adopted by 3GPP and became the LTE standard that is now used globally

NTT DoCoMo started their commercial LTE services as early as December 24th 2010 under Xi (crossy) brand with 10 MHz of frequency on band 1. On November 16th 2012 NTT DoCoMo acquired bands 19 and 21 and could offer speeds of up to 112.5 Mbps with the exception of major cities Osaka, Nagoya, and Tokyo where it obtained access to these bands on March 31st 2014. In conjunction with the launch of iPhone 5S and 5C models the company also launched service on band 3 in the cities of Osaka, Nagoya and, Tokyo and more recently in January 2015 they were also granted access on band 28, but it hasn't been commercially utilized yet.

From June 2014 onwards NTT DoCoMo has also offered VoLTE services

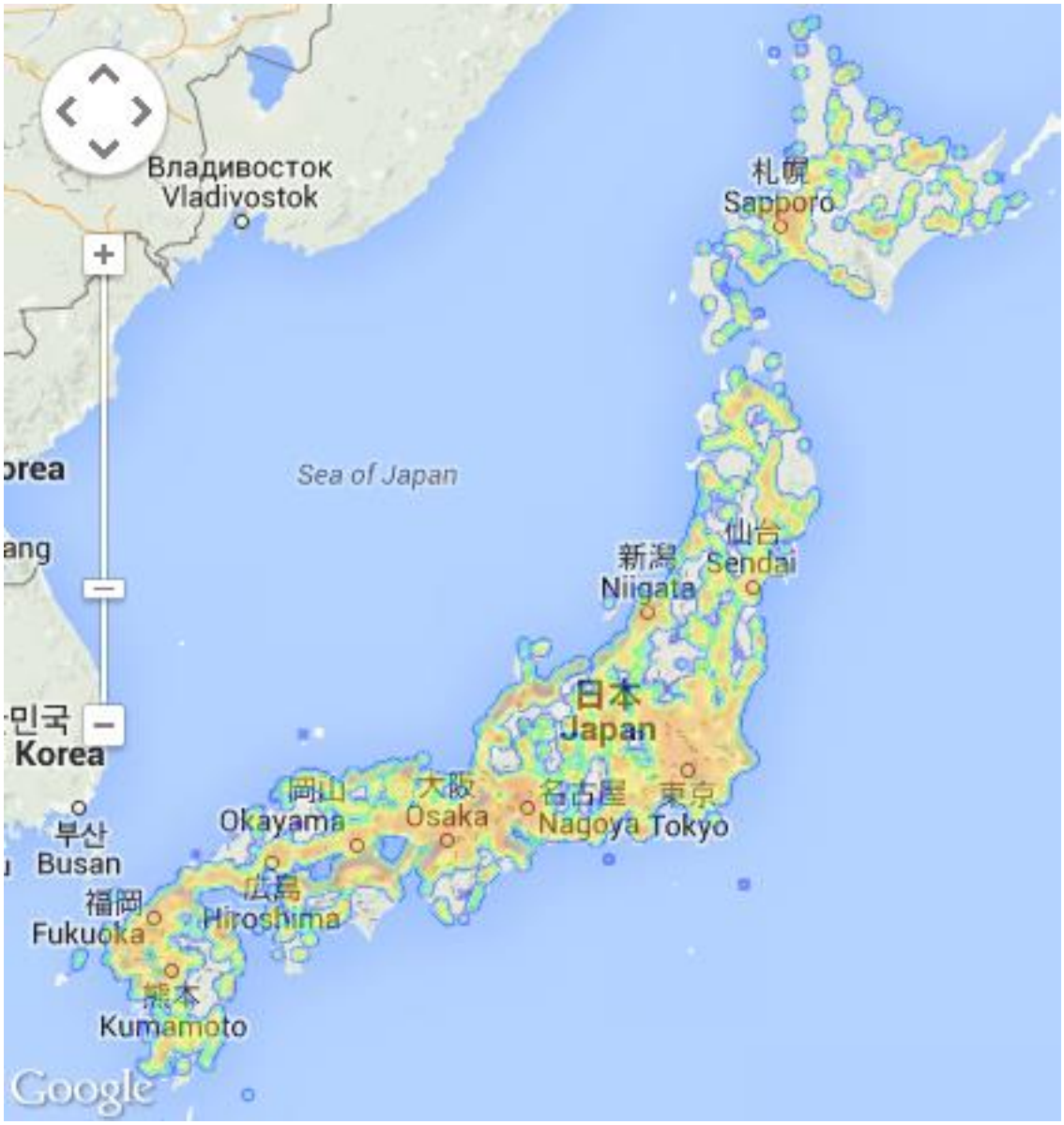
NTT DoCoMo has a multitude of bands on use depending on the geographical location nationwide coverage is provided with band 19, band 21, and band 1. Band 3 is available exclusively in Kanto, Kansai and Chubu regions thus covering major Tokyo, Osaka, and Nagoya metropolises. (Table 7)

Band	Amount of frequency	Frequency for DL	Frequency for UL	Carrier Aggregation
19 (800 MHz)	15 MHz	875-890 MHz	830-845 MHz	CA_1A_21A, 30 MHz (225 Mbps)
21 (1500 MHz)	15 MHz	1495.9-1510.9 MHz	1447.9-1462.9 MHz	
1 (2100 MHz)	20 MHz	2130-2150 MHz	1940-1960 MHz	
3 (1800 MHz) Band 3 is only available in select cities	20 MHz	1859.9-1879.9 MHz	1764.9-1784.9 MHz	CA_3A_19A, 30 MHz (225 Mbps)

Table 7. Bands, frequencies, and Carrier Aggregation used by NTT DoCoMo.

NTT DoCoMo offers only 30 MHz of aggregated frequency leading to maximum speeds of just 225 Mbps CA schemes in uses are CA_3A_19A for band 3 area and CA_1A_21A for nationwide service.

The variety of bands make UE's very specific to DoCoMo's network and make them practically unusable for any other carrier due to the fact that the carrier has only band 1 that is used widely around the world.



Picture 12. NTT DoCoMo's LTE network coverage covers around 85% of Japanese population at all times (OpenSignal [20]).

While DoCoMo's coverage is actually very good (Picture 12), the amount of subscribers and variety of bands combined with only 30 MHz CA makes the speeds in the network quite lackluster averaging at only 8.1 Mbps. By Q2 2014 NTT DoCoMo had over 26,000,000 LTE subscribers and over 95,000 LTE enabled base stations by the end of Q1 2015.

3.3.2 SoftBank

Like mentioned in the introduction, SoftBank is one of the more interesting carriers covered. Not only do they have carrier services in Japan and the US, but they also own chunks of the mobile gaming companies Gung Ho Online entertainment from Japan and Supercell from Finland.

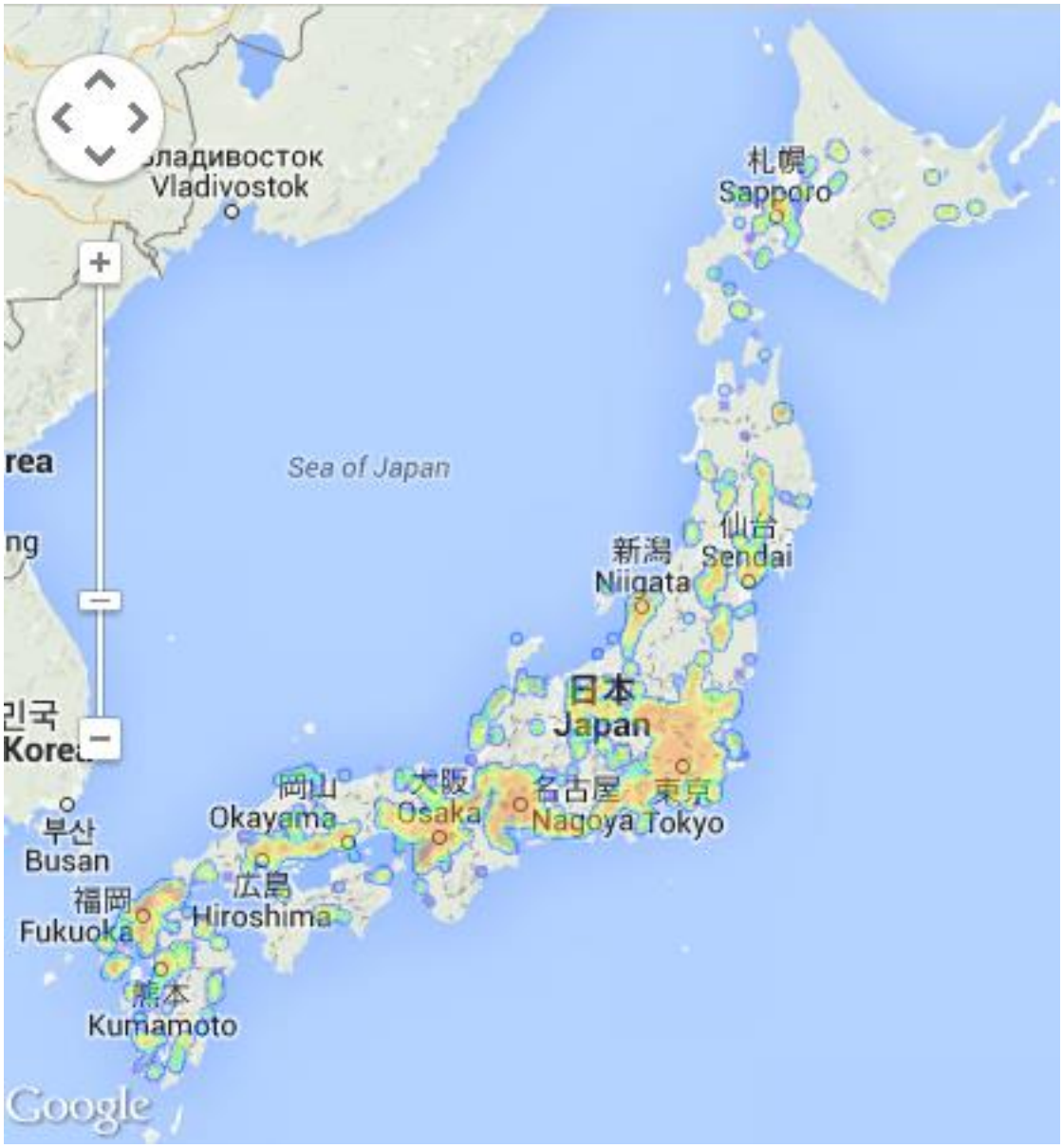
SoftBank is also the only carrier in this thesis that uses time division duplexing instead of frequency division duplexing in one of their bands. For their FDD-LTE networks SoftBank uses equipment from NSN [23, 24]

SoftBank isn't offering conventional LTE carrier aggregation, instead they are offering their own aggregated LTE and 3G connection technology from their subsidiary Wireless City Planning called AXGP that combines LTE and WCDMA bands, this maxes out at 165 Mbps DL and 10 Mbps UL leaving Softbank behind it's LTE CA rivals in terms of max speeds.

Band	Amount of frequency	Frequency for DL	Frequency for UL
1 (2100 MHz) FDD	20 MHz	2150-2170 MHz	1960-1980 MHz
41 (2500 MHz) TDD	30 MHz	2545-2575 MHz	2545-2575 MHz

Table 8. Bands and frequencies used by SoftBank.

SoftBank uses only two bands for their own service, band 1 FDD, and band 41 TDD (Table 8). The TDD band ranges from 2545 to 2575 MHz and incorporates Wireless City Planning's AXGP technology to aggregate the band with SoftBank's 900 MHz WCDMA frequency. Due to the fact that TDD is used, all of the 30 MHz frequency is used for both DL and UL in sequence allowing the full frequency to be used in either direction for example for 5ms at a time. They also have 10 MHz in band 3 (1800 MHz), exclusively for use on their subsidiary Y!mobile brand.



Picture 13. SoftBank's LTE network coverage, their network covers around 84% of Japan (OpenSignal [20]).

SoftBank’s network covers the vast majority of the Japanese population due to covering the central metropolitan areas around the country. (Picture 13)

Softbank is also offering VoLTE services to its customers

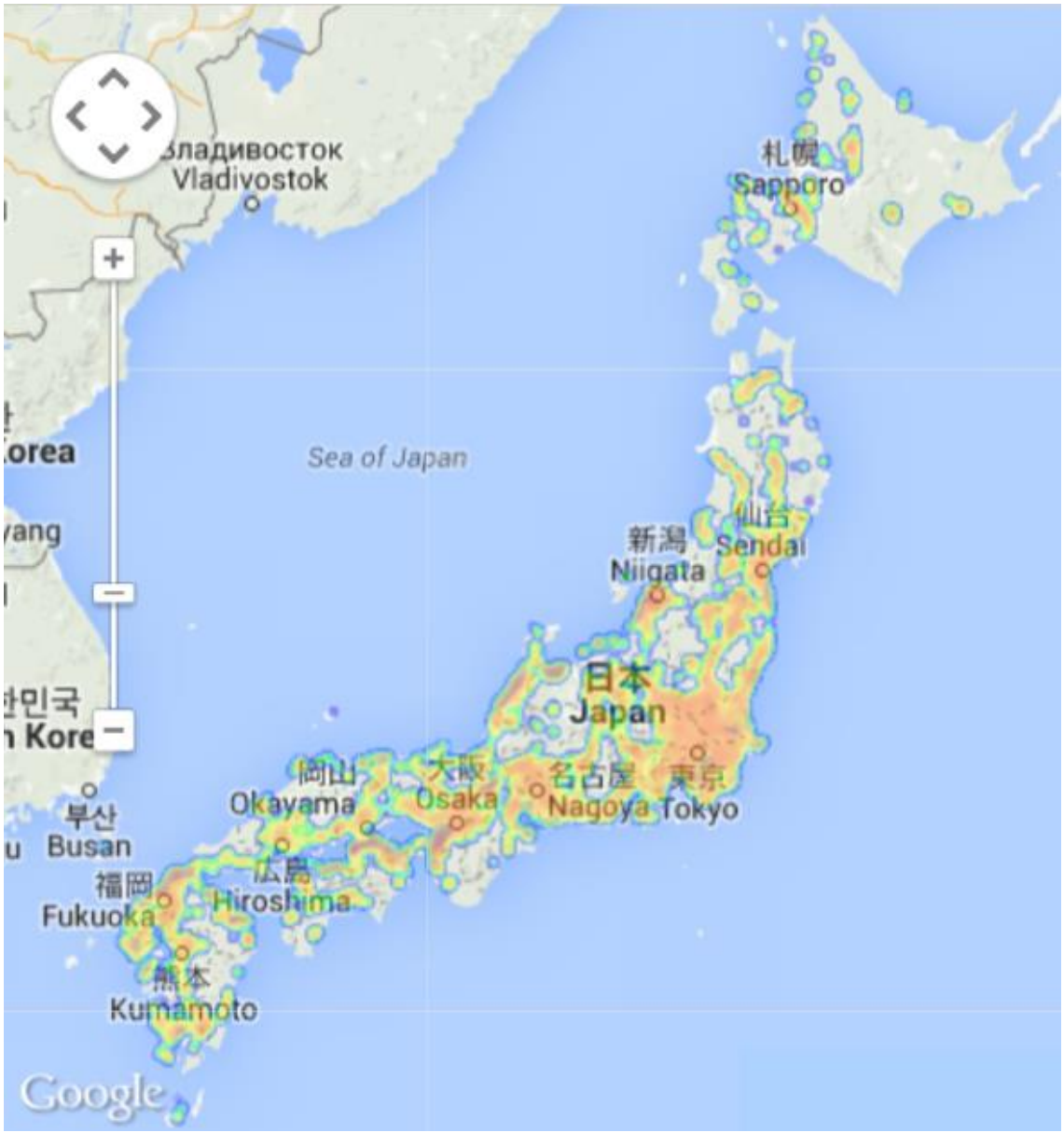
3.3.3 au by KDDI

au by KDDI is the third major carrier in Japan and like it's rivals it's offering full range of LTE services to it's customers in Japan including carrier aggregation and VoLTE. au announced carrier aggregation to it's customers on May 5th of 2014 offering DL speeds of 150 Mbps and launched it commercially on August 29th of 2014. VoLTE services were announced on October 27th of 2014 and launched on December 12th 2014.

Band	Amount of frequency	Frequency for DL	Frequency for UL	Carrier Aggregation
18 (800 MHz)	10 MHz	860-870 MHz	815-825 MHz	CA_1A_18A, 30 MHz (225 Mbps)
11 (1500 MHz)	15 MHz	1485.9-1495.9 MHz	1437.9-1447.9 MHz	
1 (2100 MHz)	20 MHz	2110-2130 MHz	1920-1940 MHz	

Table 9. Bands, frequencies, and Carrier Aggregation used by KDDI.

au is using band 18, band 11, and band 1 (Table 9). Band 1 has 20 MHz of frequency, of which 5 MHz is used as a guard band to avoid interference and thus does not carry data services. As of April 6th 2015 au has started upgrading it's services to enable the guard band to be migrated into band 1 service and offering full 20 MHz spectrum, and is now able to offer aggregated speeds of up to 225 Mbps in select areas and with select devices by aggregating bands 1 and 18 in CA scheme CA_1A_18A by using 30 MHz of frequency beating their old 20 MHz 150 Mbps LTE offerings and 220 Mbps WiMAX 2 offerings.



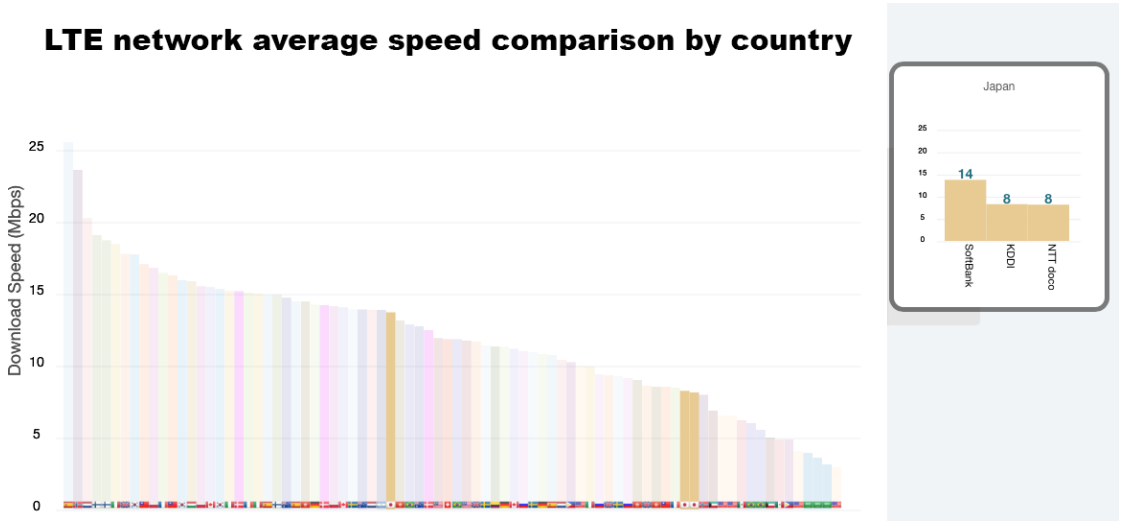
Picture 14. au by KDDI LTE network coverage covers around 90% of Japan (OpenSignal [20]).

au's LTE coverage reaches more than 90% of Japanese population wherever they go (Picture 14). The company claims that their 800 MHz network reaches up to 99% of Japanese population with maximum service speeds of 75 Mbps [25].

3.3.4 Conclusions and summary – Japan

Japan has advanced LTE networks. Japan's LTE network coverage is good 86%, which makes it world's second best on terms of LTE coverage.

The problem with Japan's LTE networks is the congested base stations. Japan has LTE subscriber rate of over 50%, and in numbers this was 51,200,000 subscribers in Q2 2014 second only to the US. Most of the users are centralized in the big cities where networks become overloaded and this results in poor performance with big carriers. [21][5] (Graph 6)



Graph 6. Average DL speeds of Japanese carriers, SoftBank comes on top with 14 Mbps average speed (OpenSignal [21]).

A very good example of this "network hotspot" problem occurred with the 2011 Great East Japan earthquake. In the aftermath of this catastrophic event the cell towers were so overloaded, that it was nearly impossible to make any calls or get connected to the Internet. In a country as crowded as Japan problems like this can easily occur and dramatically affect the performance of mobile services, even under regular circumstances.

The other major drawback with Japanese carriers is the limited frequency spectrums that they have available. The carriers only have maximum of 30 MHz of

frequency available at this time, which leads to lower maximum speeds and simultaneous users than the other countries covered in this thesis can achieve.

Technologically advanced Japan's networks are very advanced, all of the major carriers support both Cat 6 LTE-A and also VoLTE, however due to the reasons stated before the performance is far from ideal, and leaves a lot of room for improvement.

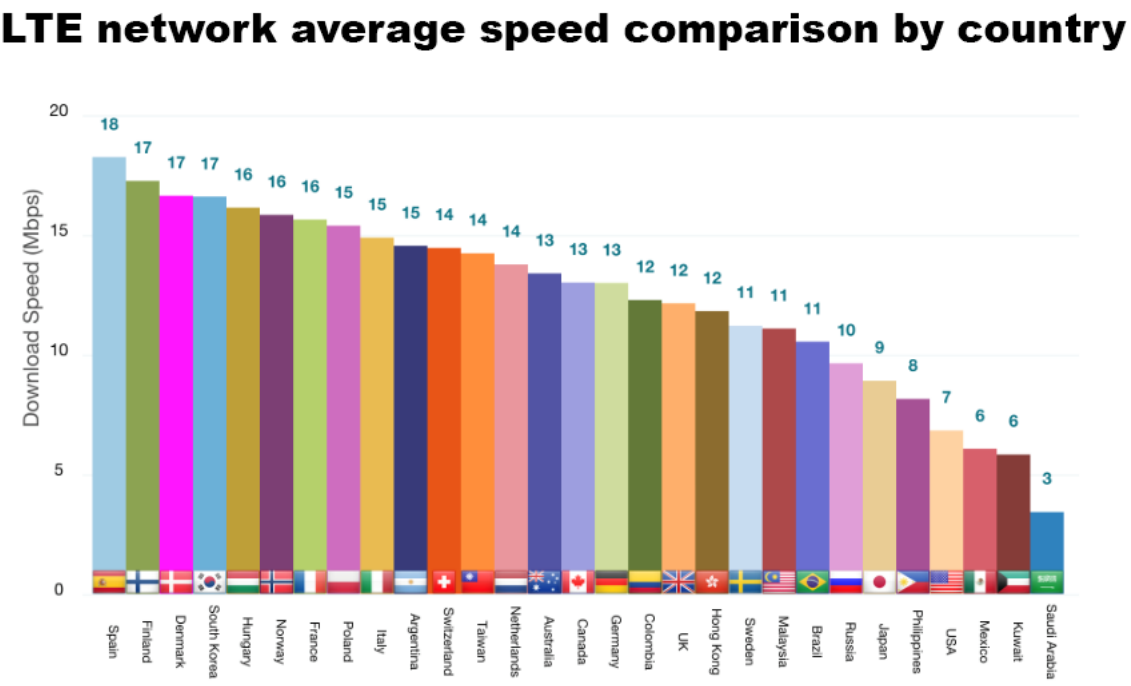
LTE penetration in the networks is high, as is the subscriber rate. The prices for LTE contracts in Japan start from around 1000¥ (10USD) for the basic fare with no included data and run to around 6000¥ (60USD)/month for a package plan with 7GB of LTE data and after that unlimited data with throttled speeds of 128 kbps. There is no unrestricted unlimited high-speed data on offer.

4 RESULTS COMPARISON

Finland has many advantages over Asian carriers. The amount of subscribers is relatively low which leads to lesser network congestion and gives better average speeds to the end users. Also LTE penetration is currently only about 25%, which also leads to less congestion. Technology wise Finland is lacking behind it's Asian rivals, but with Elisa pioneering wide scale Cat 6 carrier aggregated networks into all major cities Finland should soon get even better edge against it's Asian rivals.

South Korea is nearly neck-to-neck with Finland when it comes to average speeds. This is to be contributed to the technological level that South Korea has where it is actually unrivaled in the world. However Korean networks are much more congested and their bands and CA spectrums are unique to the carrier, which makes UE's interoperability between carriers a challenge and requires tailored models with separate antennas for each of the carriers.

In the rear is Japan, Japanese networks performed poorly in speed comparisons. This is most likely due to the amount of simultaneous users and network congestion in conjunction with having slightly older technology compared with Korea. And Japanese frequencies seem to be even more complicated than Korean ones and the carriers have less frequency to go around, which also leads to worse speeds and more congestion.



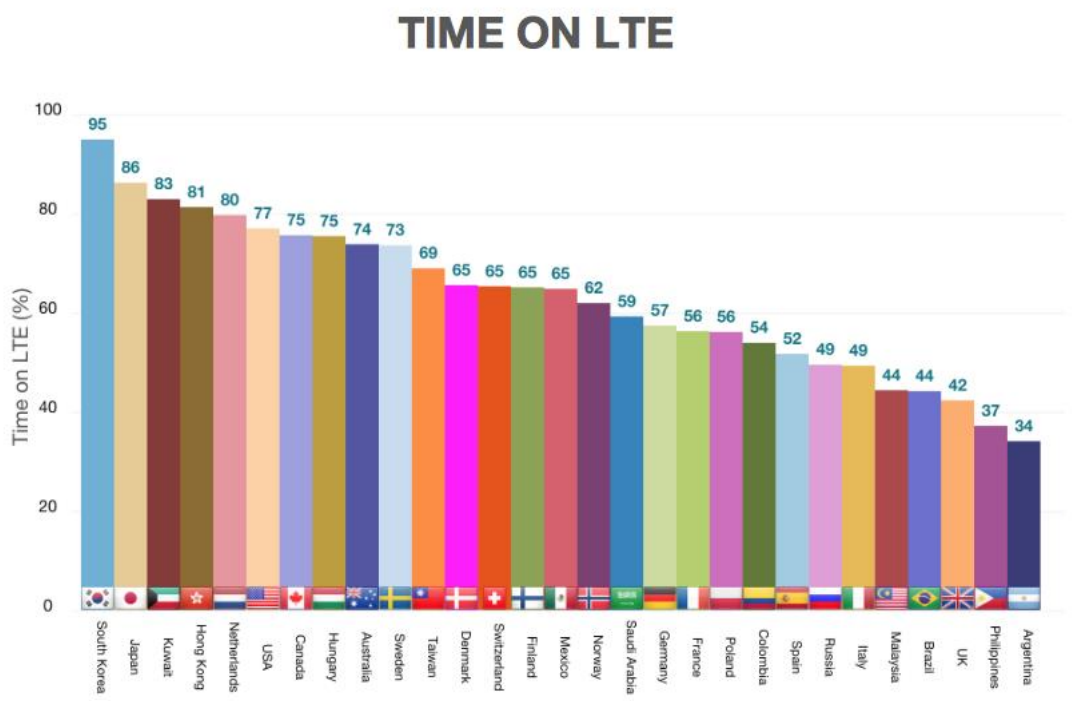
Graph 7. Average LTE speed comparison by countries (OpenSignal [21]).

In the average speed comparison between the countries, Finland is doing very well considering that it's still using older Cat 4 Services while Korea and Japan have moved on to the Cat 6 services, good networks and small subscriber numbers all help Finnish carriers to have the highest average speed of the countries at 17 Mbps, close in second was South Korea with nearly the same result. Comparatively Japan had poor performance at only 9 Mbps. (Graph 7)

Coverage wise Finland is clearly the worst with just roughly 65% of Finland covered in LTE networks. However Finland being much more sparsely populated than Asian countries this 65% coverage is actually enough to cover over 90% of Finnish population.

Korea's LTE coverage is ranking number 1 in the world, covering on average 95% of the country and LG U+ covers 99% of the country

Japan's network coverage is coming in second in the world with average of 86% LTE coverage. (Graph 8)



Graph 8. LTE network coverage by country (OpenSignal [21]).

In implemented technologies Finland is behind Korea and Japan with just Elisa starting to roll out its Cat 6 network now.

In Korea Cat 6 services have been in operation since late last year. Japan is currently sticking with slower 225 Mbps speeds due to the lack of frequency that is allocated to the carriers.

Adoption of LTE-A will take some time in Finland. First UEs supporting Cat 6 speeds were released in late 2014 with Samsung Galaxy Note 4, and the selection is still limited with most of the UEs supporting Cat 6 being expensive flagship models, so currently the amount of subscribers who can use Cat 6 in Finland is limited until the technology comes to wider and more affordable range of UEs.

This is not an issue in Korea and Japan where basically all new contracts are sold with UEs included and the UE renewal rate is much higher than Finland. And since the UEs in Asia are all carrier tailored they always support all new technologies that the carrier is offering right from the start.

In Finland LTE penetration is about 25%, which would make the amount of subscribers just around 1,300,000 in total. In Korea LTE penetration is over 70% with a total of over 35,000,000 subscribers. Japan takes the lead in subscribers with LTE penetration of around 50% and over 52,000,000 subscribers.

5 SUMMARY

Overall the findings were surprising, I didn't think that Finland had such strong networks that it's actually able to beat its Asian rivals who have more advanced networks. And it does show that even though Finland isn't one of the most advanced mobile countries any more like it was at the launch of 3G it still has very solidly performing carriers with little network congestion, so they can go head-to-head with the offerings of even the most advanced countries.

With Elisa's Cat 6 network expanding in the near future it'll be interesting to see if Finnish carriers can make more headway towards their Asian rivals. But for now Finland can't be considered as one of the countries that are spearheading mobile technologies anymore.

It'll also be interesting to see if Korea can keep up with their current pace of adopting new technologies, or will their carriers and tech companies like Samsung run out of steam before 5G networks become available for carriers around 2020 or will they continue to lead the mobile revolution into the 5G era as well.

And what role will Japanese carriers play in the future. They were vital in developing the LTE standard and SoftBank is very creative carrier with a strong vision for the future. I believe that they will also have a lot to offer in the future in terms of innovation and creativity, not only in the carrier's hardware side, but also on the software side.

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