INTERNATIONAL JOURNAL OF PROFESSIONAL BUSINESS REVIEW
JPB REVIEW
ISSN: 2525-3654
OPEN ACCESS

LTE CARRIER AGGREGATION DEPLOYMENT: FROM STANDARDIZATION TO DEPLOYMENT

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ARTICLE INFO

Article history:

Received 30 Dezember 2021

Accepted 07 February 2022

Keywords:

LTE Carrier Aggregation;
Standardization;
Deployment;
5G technology.

ABSTRACT

Purpose: The objective of this research was to investigate LTE Carrier Aggregation commercial deployment and how soon it happened after standardization finalization. Because LTE Carrier Aggregation feature was expected to be important feature there is good reason to expect its deployment for real commercial markets.

Theoretical framework: The literature at time when standardization was ongoing predicted and speculated Carrier Aggregation feature as promising deployment selection. However there is room to investigate whether Carrier Aggregation happened shortly after standard specification work finalized.

Design/methodology/approach: Used methodology was to gather network operators' and equipment manufacturers' intentions for LTE Carrier Aggregation commercial deployment purposes during and after standardization finalization. Information found from public sources where commercial deployment intentions launched by companies.

Findings: The research showed that after and already before standardization finalized there were immediate intentions for LTE Carrier Aggregation deployment. Commercial trials appeared within one year and real commercial deployments appeared within two years from standardization finalization. That means soon deployments in commercial markets when considering deployment in licensed band.

Research, Practical & Social implications: For future works there could be study why not LTE Carrier Aggregation solutions in unlicensed band was not successful and whether there will be changes when going towards 5G standard related deployments.

Originality/value: This article is an academic contribution for innovation feature commercial deployment in telecommunications industry and investigation whether LTE Carrier Aggregation feature deployment happened as soon as expected.

Doi: https://doi.org/10.26668/businessreview/2022.v7i2.0354

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LTE IMPLANTAÇÃO DE AGREGAÇÃO DE TRANSPORTADORES: DA PADRONIZAÇÃO AO DESDOBRAMENTO

Objetivo: O objetivo desta pesquisa era investigar a implantação comercial do LTE Carrier Aggregation e o quão logo isso aconteceu após a finalização da padronização. Como se esperava que o LTE Carrier Aggregation fosse um recurso importante, há boas razões para esperar sua implantação em mercados comerciais reais.
Estrutura teórica: A literatura na época em que a padronização estava em andamento previa e especulava o recurso de Agregação de Transportadora como uma seleção promissora de implantação. Entretanto, há espaço para investigar se a Agregação de Transportadoras ocorreu logo após a finalização do trabalho de especificação padrão.
Design/metodologia/abordagem: A metodologia usada foi para reunir as intenções dos operadores de rede e fabricantes de equipamentos para fins de agregação comercial do transportador LTE durante e após a finalização da padronização. Informações encontradas de fontes públicas onde as intenções de implantação comercial foram lançadas pelas empresas.
Descobertas: A pesquisa mostrou que após e já antes da finalização da padronização existiam intenções imediatas para a implantação do LTE Carrier Aggregation. Os testes comerciais surgiram dentro de um ano e as implantações comerciais reais surgiram dentro de dois anos após a finalização da padronização. Isso significa que logo as implantações em mercados comerciais quando se considera a implantação em banda licenciada.
Pesquisa, implicações práticas e sociais: Para trabalhos futuros, poderia ser estudada a razão pela qual as soluções de agregação LTE Carrier em banda não licenciada não foram bem sucedidas e se haverá mudanças quando se for para implantações relacionadas ao padrão 5G.
Originalidade/valor: Este artigo é uma contribuição acadêmica para a inovação em matéria de implantação comercial na indústria de telecomunicações e para investigar se a implantação do LTE Carrier Aggregation aconteceu tão logo o esperado.

Palavras-chave: LTE Carrier Aggregation, Padronização, Implantação, Tecnologia 5G.

DESPLIEGUE DE LA AGREGACIÓN DE PORTADORAS LTE: DE LA NORMALIZACIÓN AL DESPLIEGUE

Objetivo: El objetivo de esta investigación era investigar el despliegue comercial de la agregación de portadoras LTE y la rapidez con la que se produjo tras la finalización de la estandarización. Como se esperaba que la agregación de portadoras LTE fuera una característica importante, hay buenas razones para esperar su despliegue en los mercados comerciales reales.
Marco teórico: La literatura en el momento en que la estandarización estaba en marcha predijo y especuló con la característica Carrier Aggregation como una selección de despliegue prometedora. Sin embargo, se puede investigar si la agregación de portadores se produjo poco después de que se finalizara el trabajo de especificación de la norma.
Diseño/metodología/enfoque: La metodología empleada consistió en recabar las intenciones de los operadores de redes y los fabricantes de equipos a efectos de la agregación comercial de portadoras LTE durante y después de la finalización de la normalización. Información obtenida de fuentes públicas en las que las empresas han dado a conocer sus intenciones de despliegue comercial.
Resultados: La investigación mostró que después y ya antes de la finalización de la normalización había intenciones inmediatas de despliegue de la agregación de portadoras LTE. Los ensayos comerciales surgieron en el plazo de un año y las implantaciones comerciales reales en los dos años siguientes a la finalización de la normalización. Esto significa que pronto los despliegues en los mercados comerciales cuando se considera el despliegue de la banda con licencia.
Implicaciones para la investigación, la práctica y la sociedad: Para futuros trabajos, se podría estudiar por qué las soluciones de agregación de portadoras LTE en la banda no licenciada no han tenido éxito y si habrá cambios cuando se realicen despliegues relacionados con el estándar 5G.
Originalidad/valor: Este trabajo es una contribución académica a la innovación en el despliegue comercial en la industria de las telecomunicaciones y para investigar si el despliegue de la agregación de portadoras LTE ocurrió tan pronto como se esperaba.

Palabras clave: Agregación de portadoras LTE, Estandarización, Despliegue, Tecnología 5G.

INTRODUCTION

The focus of research is to investigate the LTE Carrier Aggregation (CA) feature commercial deployment and its relation to standardization. The intention is to show whether commercial deployment started immediately when the 3rd Generation Partnership Project (3GPP) standardization organization provided the standard specification for system construction. The LTE standard specification starts from the release 8 and switching point between the LTE and 5G is the release 15. The LTE CA specification starts from the release 10. The essential or potentially essential patent or patent application has the claim which is read on the 3GPP standard specification. The essentials are usually declared to ETSI according to IPR policy.

The prediction for CA feature deployment is clarified visiting in literature at time when the standardization work was ongoing and when going towards further developments. There was indications for coming commercials success (Wang, et al., 2013; 4GAmericas, 2014). Because users' data usage increase all time it is evident to expect success for features which increase data rates. There is also discussions (Alkhansa, et al., 2014) about LTE and WiFi coexistence and cooperation to provide multiple carriers in parallel usage. Regarding to the solutions such as LTE-U and LTE LAA the (Paolini, 2015) discusses vendors' readiness to support unlicensed band solutions. When the technology development goes towards 5G there (Calin, 2015) is indication about Dual Connectivity (DC) feature as key for further development. The (Xiao, et al., 2016) discusses the need for spectrum aggregation between Mobile Network Operators (MNOs) allowing wider spectrum usage. The LTE CA technology is also considered to be (Suryanegara, et al., 2018; Lu, et al. 2019) part in 5G development both in licensed and unlicensed spectrums. Hence, literature review and general expectation serve as basis for research question formulation: "Has the LTE Carrier Aggregation been commercially successful?". The commercial successful means LTE CA feature commercial usage in time frame when 3GPP standard specifications allowed the feature implementation in practice.

LITERATURE REVIEW

LTE CA development and technology trends are clarified from different angles when going towards different multicarrier variations including both licensed and unlicensed solutions and finally when transition happens towards 5G solutions. Findings justify CA feature development and usage needs commercially, and research question set for commercial deployment study.

The (Wang, et al., 2013) discusses about inter-site CA where Heterogeneous Network (HetNet) is constructed from macro and small cells (low power cells) such as Remote Radio Head or pico cells as inter-site cells. One component carrier (PCell) belongs to macro cell and another component carrier (SCell) belongs to small cell. The study clarifies performance of inter-site CA (UE connects both macro and small cell at same time) compared to without inter-site CA (UE connects to macro or small cell at a time) situation in downlink direction. The inter-site CA mode gives better performance results there.

The (4GAmericas, 2014) forecasts the CA to be mainstream feature in the future. There is mentioned that *"Strong collaboration across the industry for further innovations, evolutions and optimization will drive CA as a mainstream technology"*. This means cooperation needs between MNOs, network equipment, mobile phone and chipset vendors. The International Telecommunication Unit (ITU) has set data rate requirements for LTE CA release 10 which are in downlink 3 Gbps and in uplink 1,5 Gbps.

The (Alkhansa, et al., 2014) discusses about LTE-WiFi CA which is one approach where different component carriers belong to different RATs; called as multi-flow CA. It provides advantages such as fragmented spectrum usage and load balancing between RATs. LTE and WiFi have similarities at physical layer specifications, partly overlapping bandwidths and OFDMA access schemes. Network architectures support cooperation with LTE and WiFi as CA. In wireless coexistence there is need to identify (discover) nearby WiFi Access Points (APs) by the LTE eNB. LTE can borrow WiFi spectrum carriers for LTE CA. There is need to consider interference coordination and time synchronization issues.

The (Paolini, 2015) makes interviews and estimations for unlicensed spectrum usage plans by MNOs and readiness by network and handset manufacturers. MNOs see unlicensed 5 GHz spectrum usage a way to increase cellular network capacity. The same 5 GHz spectrum band is used parallel by WiFi vendors. That's lead to discussion about fair coexistence between LTE unlicensed and WiFi. The LTE unlicensed (LTE-U) and LTE Licensed Assisted Access (LAA) are alternatives. The LTE-U was mainly targeted to China, India, South Korea and USA where Listen Before Talk (LBT) is not required by regulation and shorter time to market is possible then; whereas LAA needs LBT mechanism. In 2015 LTE-U was started to be in commercialization phase while the LAA was waiting for standardization and commercialization. All the vendors had readiness and plans in their roadmaps to provide such technologies.

The (Calin, 2015) discusses technologies for future wireless broadband evolution. It is sure that data transmission needs will increase because users want to be always connected. Both wireless and wired broadband solutions are needed when consuming various services. In addition to CA as important feature there are several features available in LTE for improving spectral efficiency and capacity. Multiple Input Multiple Output (MIMO) where 20 % capacity gain is estimated when four spatial streams are used. The Coordinated Multipoint Transmission and Reception (CoMP) where 10 % capacity gain is estimated in the 3GPP release 11. The Adaptive Antenna Array (AAA) or sectorization solution where 40-100 % capacity gain is estimated depending on deployment scenarios. The Enhanced Inter-Cell Interference Coordination (eICIC) where 25 % capacity gain is estimated. In addition to, HetNet and centralized baseband processing are listed. In the beginning of 5G system definition there were assumptions to which direction technology selection goes in order to fulfil requirements for the system. There were expectations that the CA and DC will be key features in 5G because MNOs can benefit what are already available in 4G and where to investments have already done. In addition to, LTE and WiFi combination with 5G forming CA and DC predicted to be in 5G system. Small cells and HetNets are expected to be key concepts in 5G as well.

The (Xiao, et al., 2016) discusses the CA between MNOs where each MNO operates in their licensed spectrum and aggregate licensed spectrum belong to other MNOs. Spectrum sharing is based on mutual agreement between MNOs. The arrangement gives wide frequency band for higher speed data transmission. The arrangement comprises HetNet where dynamic spectrum aggregation with own MNO macro cells and other MNO low power cells are constructed. When additional capacity is needed by MNO there is need to find capacity from other MNO as partner for pairing. When the UE uses other MNO's spectrum the other MNO charges for UE's own MNO. There is seen issue for pricing which need to be solved then. The power control is also thing to be solved because each MNO have own power control for optimizing used power.

The (Liu, 2016) handles technology trends when going towards 5G era. There are various needs coming from various application areas relating to enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra-Reliable Low-Latency Communication (URLLC). Those are estimated to lead 1000 times mobile data traffic growth by 2020 and therefore require new solutions and innovations. In small cell environment there are solutions in research for frequency ranges below 6 GHz and above 6 GHz (mmWave). The CA is considered to keep important role in its various forms such as LTE and WiFi aggregation, LAA, DC and multiple band aggregation including above 6 GHz area. In small cell environment there are potential challenges with interference management and multiple cell coordination, for example. There are also new multiple access methods available for spectral efficiency improvement where one is Non-Orthogonal Multiple Access (NOMA) where multiple users are assigned to same resource.

The (Salem, et al., 2016) discusses 5G-Unlicensed (5G-U) and its possible improvement compared to LTE LAA. General interest for unlicensed band has increased in CA and small cell environment solutions. The licensed band considered to be the main resource and the unlicensed band can be used to alleviate increased traffic demands. The challenge in the LAA is fair coexistence with WLAN because operating at same band. There is mentioned that there is no mechanism available for inter-LAA MNO coexistence. Taking earlier studies and knowledge into account there is proposed mechanism for improving situation between 5G-U and WLAN fair and efficient access.

The (Nanjundappa, et al., 2018) discusses Multi-RAT CA approach. The 5G architecture facilitating and optimizing plug and play model. In the 3GPP there is set that 5G comprising Non-Standalone (NSA) and Standalone (SA) modes. The NSA mode consists of supporting cooperation with other RAT than 5G. The SA mode consists only 5G RAT including Centralized Unit (CU) and Distributed Units (DU) as remote sites below the CU. The DU is assigned dynamically based on operation conditions and requirements for used service. Dedicated DU may operate relating to Machine Type Communication (MTC), Device-To-Device (D2D), Vehicle-to-Everything (V2X), LTE-5G DC and LTE-WiFi aggregation service. The throughput and latency improvements are possible when dedicated DU is used for certain service. This kind of arrangement may help MNOs with their requirements.

The (Huo, et al., 2018) discusses 5G and WiFi coexistence with cost efficient physical layer design aspects. In 2015 there were 5G development targets for eMBB, URLLC and mMTC set by the ITU. In 2016 Federal Communications Commission (FCC) adopted new Upper Microwave Flexible Use Service. In 2017 the first New Radio (NR) standard specification approved. The 5G HetNets started to come reality and cause more complexity from implementation viewpoint because of need to include more radio technologies in the UE. The 5G UE design causes challenges compared to 4G from antenna design, RF design, baseband design and PHY-MAC co-design viewpoint. Also, high demanding applications and services bring further challenges. The mmWave usage in 5G causes challenges such as high propagation loss, serious human blockage, human shadowing issues, high penetration loss and weaker diffraction capability. The WiFi technology usage with 5G is important when the 5G-LAA is reality once standardization is ready. It is based on current LTE LAA techniques. There is prediction that 5G-LAA deployment will exist soon. The 5G mmWave with WiFi WiGig provide more powerful aggregated bands and there is estimated 10 times performance improvement for rate and latency compared to LTE LAA. Cellular and WiFi co-design is challenging due to resource competition between standards 3GPP and WiFi where both RF parts are situated in limited HW space. There is also needed space for mmWave Beamforming (BF) arrangement which causes implementation challenges as well. There are requirements for MAC for enabling standalone and cooperation functions between cellular and WiFi. There is also needs for arrangement where CA happens below 6 GHz and above 6 GHz frequencies where both covering licensed and unlicensed bands.

The (Suryanegara, et al., 2018) discusses innovation agendas towards 5G. Scientific knowledge is mentioned as key factor when developing new telecommunications generations in innovation process. Totally 380 research publications from 2009 to 2016 have been studied. Grouped for 39 categories with their importance factor: high, medium and low influence of innovation. One observation is that mmWave and Energy have highest influence for 5G development. The LTE including LTE-U is also found as high influence when developing 5G. Other high influence technologies are Power Control, Interference, HetNet and MIMO. One interesting thing is that WiFi is not considered as high influencing feature in 5G development but only low influence. On the other hand there is HetNet and unlicensed approach covered in LTE category.

The (Ancans, et al., 2019) discusses LTE and WiFi usage for Vehicle-to-Everything (V2X) communication from technical and economical viewpoint. Used parameters reflect technology efficiency and cost related issues. Technical parameters are throughput and response time. Economical parameters are capital investment and operating costs. There is also offloading parameter representing certain characteristics for WiFi offloading in the case of LTE and WiFi cooperation. The cooperation is suitable because they provide corresponding transmission speed and delay. WiFi with unlicensed band are usable widely and LTE coverage is widely available. Data traffic can be offloaded from LTE to WiFi whenever available. When LTE coverage is missing there is possible to use WiFi instead. Perhaps LTE and WiFi cooperation is the cheapest way for massive data transmission.

The (Lu, et al. 2019) discusses about the 5G deployment issues for licensed and unlicensed bands which likely needed due to increasing bandwidth needs. In 5G there is need for more bandwidth due to different kind of applications and increasing amount of different kind of subscribers. This may cause MNOs to take licensed mmWave bands into use as well. In addition to, the IEEE provides unlicensed mmWave bands for next generation WiFi and D2D usage. The legacy LAA may provide possibilities and therefore LTE-U/LAA would be extendable for higher bands in 5G. There is handled CA solution New Radio Unlicensed (NR-

U) i.e. 5G-U where anchor carrier is on licensed band and secondary carrier is on unlicensed band. Today's research is mostly targeted to physical and protocol layer aspects whereas NR-U offloading has not been investigated so deeply yet. Further research for practical solutions where multiple streams are handled by different RATs is recommended.

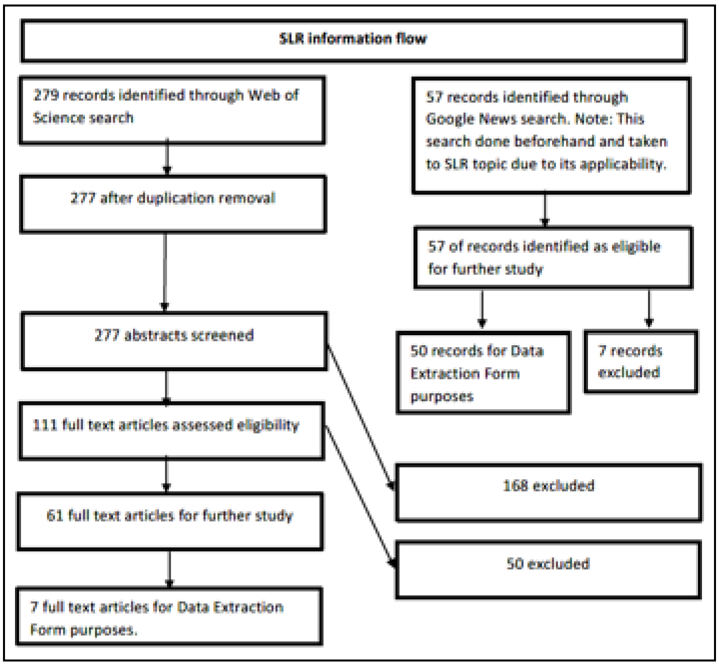
METHODOLOGY AND RESULTS

LTE CA commercial deployment research is conducted using Systematic Literature Review (SLR) from research articles and Google News search. In the SLR focus is taken how the features are commercially deployed according to literature i.e. how soon there are deployment indications when 3GPP standard specifications are ready. The principles and reporting methods for the SLR follows (Moher, et al., 2009; De Vries, et al., 2015) approaches applicable way. The articles where commercial deployment or commercial importance of specific features are speculated are counted for further investigation. All the certain LTE features or technologies are taken into account even the feature under deeper investigation is LTE CA. Reason is to check and ensure if they also include indications for LTE CA feature deployment direction.

The research question leads to keyword selection in the SLR. The database used for search is Web of Science and keywords are set the following way: ((“carrier aggregation” OR “LTE”) AND “commerc*”). The Web of Science search resulting 279 articles which are sorted according to the Figure 1. The criteria for excluding Abstracts when going Full text article investigation were: Out of technology, No commercial deployment aspect or No full text article available. The criteria for excluding Full text articles when going to more detailed investigation was: Out of technology or No commercial deployment aspect. Finally, 7 articles selected and included into Data Extraction Form (DEF) coding. One observation is that LTE CA commercial deployment may not be present widely in research articles.

The complementary search technology used is Google News search. In the search there is picked year milestones from LTE CA commercial deployments or deployment intentions for different entities. The Google News search for further investigation is also considered in the Figure 1. Totally 57 records identified for further investigation. Note that there are potentially more than 57 records for further investigation but reduced due to content overlapping and repetition relating to feature news. Finally, 50 records selected and included into DEF coding. Those 7 records excluded to be Out of technology because they handled 5G technology and the SLR focus was mainly the LTE CA technology. Some borderline cases allowed to go forward because they belong to E-UTRAN New Radio - Dual Connectivity (ENDC) where LTE eNB acts as master node and 5G gNB acts as secondary node. On the other hand, the ENDC is also considered to be the first commercial solution in 5G technology. On the other hand, there is good to see that LTE DC itself was not ready for commercialization in early phase but came applicable when 3GPP standard was ready for 5G to establish 5G New Radio (NR) implementations.

Figure 1. Information flow in SLR.



Source: the author.

The DEF is presented in the form of Table 1 where the entities for current or near future commercial deployment indication are listed in the columns: Operator (MNO), eNB, UE, Chip or HW other. Deployment column indicates: Commercially (already deployed), Trial/Test (test is done using commercial or almost commercial entities), Intention/Prediction (deployment plans in near future), Challenges (speculation about challenges to be solved) and Standardization (remarkable standardization milestone). Country column: Country where entity deployment happened, Question mark indicates that no specific country identified or may be applicable worldwide. Year column: Year when deployment happened, Question mark indicates unknown or undefined year. Technology (Techn.) column: technology abbreviation. Those all are selected to the DEF because they form different CA solutions where LTE technology is at least partly involved.

Table 1. Data Extraction Form (Continues on next page).

Numb	Techn.	General	Operator	eNB	UE	Chip	HW other	Deployment	Country	Year
1	LAA	Network generally	yes					Commercial	USA	?
2	LAA	Off the shelf hardware					yes	Commercial	?	?
3	LWA	LWA=LTE+WiFi		yes	yes		yes	Commercial	Taiwan	2017
4	CA	Commercial PA LTE-A			yes		yes	Commercial	?	?
5	LWA	LWA=LTE+WiFi	yes					Commercial	Taiwan	2017
6	CA	With 127 operators	yes					Commercial	61 countries	2017
7	CA	Technical challenges						Challenges	?	?
8	CA	Up to 100 MHz	yes					Intention	USA	2011
9	CA	Way to increase speed	yes	yes	yes			Intention	?	2011
10	CA	Boosting DL speed	yes					Intention	USA	2011
11	CA	Doubling DL speed	yes	yes	yes	yes		Intention	USA	2011
12	CA	Cat 4 - 150 Mbps				yes		Intention	?	2012
13	CA	Begin LTE-A trials	yes					Trial	USA	2012
14	CA	100 MHz BW - 1Gbps						Test	?	2012
15	CA	First ever tester					yes	Test	?	2013
16	CA	150 Mbps	yes		yes			Intention	Korea	2013
17	CA	Commercial test solution	yes	yes				Commercial	?	2013
18	CA	World's first provider	yes					Commercial	Korea	2013
19	CA	Operator + UE	yes	yes				Commercial	USA	2013
20	CA	3 carriers - World's first	yes					Trial	Korea	2014
21	CA	CA and MIMO - 3.78 Mbps	yes	yes				Test	Korea	2014
22	CA	20 MHz+10 MHz - 225 Mbps	yes					Commercial	Korea	2014
23	CA	RRH 50 MHz		yes				Commercial	?	2014
24	CA	3 cc-Cat 9-450 Mbps-Tester					yes	Test	?	2014
25	CA	3 cc - 300 Mbps - World's first UE			yes			Commercial		2014
26	LAA	New small cell technology show.		yes				Trial	USA	2015
27	LAA	Live LAA lab tests. 450 Mbps.	yes					Test	Canada	2015
28	CA	CA with 4x4 MIMO demo. 600 Mbps.	yes	yes				Trial	Korea	2015
29	CA	3 cc. TDD inter band.	yes	yes		yes		Commercial	China	2015
30	LAA	LAA wirh 5G and DC. Shows way to 2020.	yes	yes				Trial	Japan	2015
31	LAA	Small cell with LAA and WiFi demo.		yes	yes			Trial	China	2015
32	CA	3 cc. FDD/TDD. Demostration.	yes	yes			yes	Trial	Hong Kong	2015

Source: the author.

Table 1. Data Extraction Form (Continues from previous page).

Numb	Tech.	General	Operator	eNB	UE	Chip	HW other	Deployment	Country	Year
33	CA	3 cc. CA is important part in 4G way.	yes					Trial	China	2015
34	CA	5 cc. World's first. 4 separate bands.	yes	yes				Test	Australia	2015
35	CA	3 cc TDD as industry's first. 428 Mbps.	yes	yes		yes		Trial	Korea	2015
36	LAA	LTE-U could be faster market than LAA.	yes			yes		Test	Germany	2016
37	CA	More 4G than 3G devices are coming			yes	yes		Commercial	India	2016
38	CA	3 component carriers - Over 300 Mbps	yes		yes			Test	USA	2016
39	CA	CA+CoMP+MIMO+beamforming - 2 Gbps	yes					Intention	USA	2016
40	LTE-U	90% traffic on unlicensed by 2020						Prediction	?	2016
41	CA	Improve customer experience in Moscow	yes					Commercial	Russia	2016
42	CA	3 carriers - Over 200 Mbps	yes	yes				Commercial	USA	2016
43	CA	5 carriers - 3 carriers with MIMO	yes		yes			Commercial	Korea	2017
44	LAA	LAA+MIMO+256QAM - 1 Gbps	yes	yes		yes		Commercial	Australia	2017
45	LAA	Go with LAA and skip LTE-U.	yes					Intention	USA	2017
46	CA	Cat 18 - 6 carriers - 1.2 Gbps			yes	yes		Commercial	?	2017
47	LAA	Way to provide 1 Gbps - Generally						Intention	?	2017
48	DC	5G DC trial - 20 Gbps - Two 5G gNBs	yes	yes	yes			Trial	Korea	2017
49	LAA	5-10x increasing in speed with LAA	yes					Commercial	USA	2018
50	CA	CA and MIMO - 20 streams - 2 Mbps				yes		Commercial	?	2018
51	LTE-U	FCC approved first devices		yes	yes			Commercial	USA	2018
52	LAA	LAA in 24 markets	yes					Commercial	USA	2018
53	LAA	LAA - 5 cc	yes					Commercial	Hong Kong	2018
54	CA	CA - 5 carriers - 1.5 Gbps	yes		yes			Intention	Singapore	2018
55	LAA	CA - 6 cc - 1.45 Gbps	yes	yes		yes		Commercial	USA	2018
56	DC	ENDC	yes					Test	USA	2018
57	DC	ENDC		yes	yes			Standardization	Italy	2018
58	DC	NR-U. Study item Rel16. NSA and SA.						Standardization	Germany	2019
59	DC	ENDC	yes					Commercial	USA	2019
60	LAA	mmWave and NR-U study items						Standardization	?	2019
61	LAA	LAA and NR-U						Standardization	?	2019
62	DC	ENDC. World's fastest 5G. 4.7 Gbps.	yes	yes				Test	USA	2020
63	5G	Rel16 finalized. Key is NR-U. SA and NSA.						Standardization	?	2020
64	5G	5G SA CA test. 2.5 Gbps.		yes		yes		Test	China	2020

Source: the author.

LTE CA commercial deployment news started in 2011. Years 2009 and 2010 were silent from remarkable deployment news. Some pickings in 2011 show that TDD LTE CA usage (Klug, 2011) planned in the USA. LTE Advanced take role with current WiMAX network. The (Rickläs, 2011) expects LTE CA to be development direction because it can use different frequency bands because wide continuous band is not always available. Another option would be MIMO but there is challenges to get more than two antennas in the UE. The (Dano, 2011) predicts LTE CA deployment in 2012/2013 and its needs for 700 MHz and Advanced Wireless Services (AWS) spectrums combination. The (Goldstein, 2011) speaks about LTE downlink speed doubling by using unpaired 700 MHz spectrum with AWS spectrum. Because of this there is need for chipsets, handsets and base stations to utilize additional spectrum. It means that commercial deployment for customers is ready around in 2014.

In 2012 the (Parker, 2012) reports LTE Advanced chipset supporting LTE CA launch. In addition to, LTE Category 4 chipset was launched with maximum data rate 150 Mbps. There are supported totally 40 frequency bands worldwide for Original Equipment Manufacturers

(OEMs) selection based on countries. The (Gomba, 2012) indicates MNOs' LTE Advanced trials towards launching intention in 2013. Earlier network technology is updated with LTE release 10 equipment. The (EDN, 2012) concentrates testing equipment deployment for LTE CA which is needed at MNO, network equipment vendor and UE side. This needs several different test cases with various frequency bands. There is provided testing environment to fulfill needs for storing results for later and detailed analysis.

In 2013 started to launch actual commercial deployments. The (Hill, 2013) presented radio frequency tester for LTE CA. The physical layer tester for FDD inter-band and intra-band CA solutions. Principle is to simulate call with real UE. The (Middleton, 2013) reports that MNO provides increasing data rate in downlink using LTE CA in metropolitan area. It happens with solution where 20 MHz bandwidth in 1800 MHz band and 10 MHz bandwidth in 800 MHz band are used. Result is 225 Mbps data rate. Naturally network equipment vendors are ready to provide upgrades enabling LTE CA. The (Anite, 2013) presented commercial solution for LTE CA MNOs and network equipment vendors testing purposes. Measurement and monitoring are possible for component carriers and their different quantities and parameters. The (Netmanias, 2013) indicates MNO which was the first LTE CA service provider in the world. The first deployment setup is constructed with two 10 MHz component carriers providing 150 Mbps downlink data rate. Plans for year 2014 is 10 MHz and 20 MHz component carriers providing 225 Mbps downlink data rate and for year 2015 10 MHz, 10 MHz and 20 MHz component carriers i.e. three component carriers providing 300 Mbps downlink data rate. The (Converge, 2013) mentioned LTE CA capable UE launching.

In 2014 the (Korea, 2014) presented pilot for three component carriers. It provides 300 Mbps downlink data rate which is four times higher compared to basic LTE data rate. The (Converge, 2014) presented test to achieve 3,78 Gbps downlink data rate in cooperation with network vendor and MNO. This is achieved with solution where ten 20 MHz component carriers are aggregated. FDD and TDD spectrums with MIMO technology are used. The (Mallinson, 2014) stated that three component carriers is target for MNO in 2015. There is mentioned target to develop towards three component carrier launch by chipset vendor. The (Telecomlead, 2014) presented 60 MHz aggregated bandwidth to lead 450 Mbps downlink data rate. It is achieved with LTE and TD-LTE aggregation. This is supported by the category 9 UE. The (Hill, 2014) defines tester for three component carriers providing protocol and RF tests for category 9 devices. The (McGlaun, 2014) defines likely the world's first three component carriers LTE UE providing 300 Mbps downlink data rate. This kind of data rate means 700 MB video downloading within 19 seconds.

In 2015 the (Scales, 2015) presented network vendor's solution for LAA where secondary carrier establishes small cell in 5 GHz unlicensed band shared with WiFi. Intention is to cover indoor this way with solution providing fair spectrum access both LAA and WiFi. The (Aittokallio, 2015) presented LAA testing with network equipment vendor, chipset vendor and MNO with 450 Mbps data rate. Primary licensed carrier was 20 MHz and secondary unlicensed 5 GHz carrier was 40 MHz. The (Waring, 2015) reports MNO's and network equipment vendor's achievement for 600 Mbps data rate using LTE CA and 4x4 MIMO. Using 4x4 MIMO in 20 MHz bandwidth offers 300 Mbps data rate and applying CA resulting 600 Mbps data rate. The UE side 4 antennas are achieved by simulator. The (DeGrasse, 2015) reported commercial solution for three component carriers. The solution is inter-band CA in TDD. The solution is done in cooperation with network equipment vendor, MNO and chipset vendor. The (Telecomlead, 2015) reported demo with network equipment vendor and MNO for 5G LAA solution providing 10 Gbps data rate in FR1 (Frequency Range 1). This is the first step towards intended 5G network launch in 2020. The (DeGrasse_2, 2015) presented LAA and WiFi demo for small cell purposes by network equipment vendor and MNO. Hence, question is about unlicensed spectrum usage in secondary component carrier which they see likely solution for small cell environment and they are tested it extensively for that reason. The (Ericsson, 2015) reported network equipment vendor's and MNO's demo for three component carriers in FDD-TDD environment. The demo happened in live network. The (Waring_2, 2015) reports MNO's LTE CA launching in 17 cities. They keep mentioned technology advantageous for data rate with increasing HD video transmission. The (Saarinen, 2015) told that network equipment vendor and MNO have achieved five component carriers testing. Five component carriers provide 100 MHz bandwidth which is maximum specified in the 3GPP LTE Advanced standard specification. They achieved 950 Mbps downlink data rate with 256 QAM modulation. The (Nokia, 2015) reported network equipment vendor's, MNO's and chipset vendor's demonstration for three component carrier solution in TDD environment where 256 QAM is used. They achieved 428 Mbps data rate.

In 2016 the (Alleven, 2016) reported LAA tests performed by MNO and chipset vendor. It also speculates that the LTE-U which developed outside the 3GPP standardization enters faster to market than 3GPP standardized LAA where deployment is expected in 2017. There is also achievement where LAA and WiFi fair coexistence in 5 GHz band demonstrated. The (Gubta, 2016) reported that chipset vendor indicating 4G device sales exceeding 3G device sales. The chipset vendor has good readiness to provide LTE CA capable chips for UE vendors. The (Dano, 2016) indicated MNO's three component carriers testing. They admit the tests but do not comment more yet. There is also mentioned that one MNO has successfully tested three component carriers with commercial UE. The (Meyer, 2016) reported that 5G demonstration done with MNO and network equipment vendor. Test carried out in soccer tournament and beam switching is used where transmission can be directed towards target device. The (Kinney, 2016) analyzed unlicensed spectrum possibilities and predicted its share to be even 80-90 % from all data transmission by 2020. Hence, unlicensed band solutions such as the LTE-U is expected to take role from traditional WiFi. In addition to MNOs' investment to WiFi technology they will have more focus for LAA, LTE-WLAN Aggregation (LWA) and LTE WLAN Radio Level Integration with IPsec Tunnel (LWIP) technology as well. Possible application areas are small cells and enterprise solutions. The (Telecomlead, 2016) reported FDD-TDD CA deployment by MNO with network equipment vendor for increasing coverage and capacity. The same players are planning to demonstrate three component carriers FDD solution. Those are making continuum towards 5G solutions next. The (Businesswire, 2016) defines demo for three component carriers by MNO and network equipment vendor in stadium environment. Commercial UE used and 230 Mbps data rate reached.

In 2017 the (Cision, 2017) reported MNO's test for five component carriers in live network. In addition to, three component carriers with 4x4 MIMO are tested. In addition to, the LAA demonstration with 4x4 MIMO performed with other telecommunication players achieving 1 Gbps data rate. The (RCRWirelessNews, 2017) reported the first gigabit LTE launch commercially by MNO in cooperation with network equipment and chipset vendors. The feature combination was CA with LAA, 4x4 MIMO and 256 QAM modulation. The (Alleven, 2017) reported MNO's selection of LAA instead of LTE-U. The LTE-U was earlier in market than LAA but they see that LAA will provide better capability. The LAA will be also default selection over WiFi because it is better from interference management viewpoint due to signaling solutions. They have tested four component carriers with LAA. The (RCRWirelessNews_2, 2017) reported trial where six component carriers gave 1.2 Gbps data rate, 20 MHz bandwidth per carrier. They said it is the first in telecommunications industry. The test carried out by testing equipment vendor with UE vendor. The (Kinney, 2017) discusses about gigabit LTE achievement using LAA as one part. There have been related tests in many continents. Gigabit LTE is said to be one step when going towards 5G. The (ZDNet, 2017) reported 5G DC testing where 20 Gbps downlink data rate is achieved. This trial is performed by MNO and network equipment vendor.

In 2018 the (Alleven, 2018) reported that MNOs' LAA commercial deployments continues. The (Gartenberg, 2018) reports chipset vendor's launch of 2 Gbps downlink data rate modem for LTE which is path towards 5G. The chipset supports seven component carriers. In addition to, it supports five component carriers and 4x4 MIMO which means 20 simultaneous LTE streams. This can be considered also the way towards 5G. The (Brenner, 2018) reported chipset vendor's way when developing LTE-U and LAA solutions, and when going towards 5G. That means investments and commitments for R&D and new innovations generation. At same time the competition in industry level is tight and product cycles tend to be shorter. When going towards 5G there is an evolution path from LTE technology and revolution path including dedicated solutions for 5G NR. The (Alleven_2, 2018) informs LAA capable network usage in 24 markets during 2018 and there are several commercial UEs available providing theoretical 1 Gbps data rate. The (Marketing, 2018) reported live LAA network deployment. The solution is constructed with five component carriers, 256 QAM modulation and 4x4 MIMO. The (Telecomlead, 2018) reported MNO's LTE achievement with network equipment vendor using five component carriers where 1,5 Gbps data rate achieved. There is an estimation that vendors will provide UEs for those data rates in 2019. The (Verizon, 2018) mentions that the best LTE network is basis for the best 5G network. MNO, network equipment vendor and chipset vendor achieved 1,45 Gbps using LTE six component carriers in live network. The LAA was part of construction with four LAA carriers. The (Jones, 2018) indicated MNO's intention for 5G DC test using non-standalone ENDC solution. Target is to launch 5G commercially in 2019. The (Alleven_3, 2018) reported that the 3GPP has decided a work item for 5G NR unlicensed spectrum study; called NR-U. There are five scenarios including non-standalone and standalone solutions where standalone is particularly under interest. Even there is interests for unlicensed spectrum the licensed spectrum remains as main thing from MNOs' viewpoint because it is better under control.

In 2019 the (Kinney, 2019) mentioned current activities in the 3GPP 5G development. There is study whether NR-U could be on 5 GHz and 6 GHz bands. Intention is potentially included into 3GPP release 16 standardization work. The (Kinney_2, 2019) discussed about DC importance. Currently deployed ENDC is based both LTE and 5G NR radio technologies. Received streams are aggregated in the UE constructing total aggregated data rate. The (IEEE Spectrum, 2019) speaks about needed spectrum when going from LTE to 5G usage. There is lack of free spectrum below 6 GHz. Due to that reason the 3GPP standardization is looking after mmWave frequencies i.e. FR2 (Frequency Range 2 above 6 GHz) usage for 5G. Another option is to take unlicensed band to use where experiences from LTE LAA development are utilized with 5G NR-U. The NR-U includes challenges and complexities where the 3GPP standardization members have to consider pros and cons when going forward in the standardization work. The (Alleven, 2019) reports 5G NSA deployment and speaks how 5G SA solution providing higher data rate and lower latency. Pure 5G NR provides solutions also for URLLC, mIoT and V2X features, which are considered main features in the 3GPP release 16.

In 2020 the (GlobeNewswire, 2020) reported network equipment vendor's achievement for 4,7 Gbps data rate using commercial solution where the ENDC used with MNO. The construction was LTE 40 MHz bandwidth and NR mmWave 800 MHz bandwidth, including eight 100 MHz bandwidths. The (Kinney, 2020) reported about the 3GPP 5G NR release 16 standardization finalized. Due to COVID-19 pandemic the finalization done in remote meetings and there was speculation about release 17 standardization work delay due to pandemic. The (Hardesty, 2020) informed 5G FDD-TDD SA CA achievement in cooperation with network equipment vendor and chipset vendor in laboratory environment. They achieved 2,5 Gbps data rate. The 5G CA deployment for live network is expected before end of 2020 and continues in 2021.

DISCUSSION

The Table 2 presents situation where CA feature related declarations and commercial deployment have collected to same timeline on year basis according to investigation. The CA feature related IPR declarations have clarified from ETSI data base where from over 17000 LTE declarations clarified between years 2007-2017. The arrows present ways from Standardization finalization towards Commercial deployment.

Table 2. LTE Carrier Aggregation Declaration year – Release – Deployment

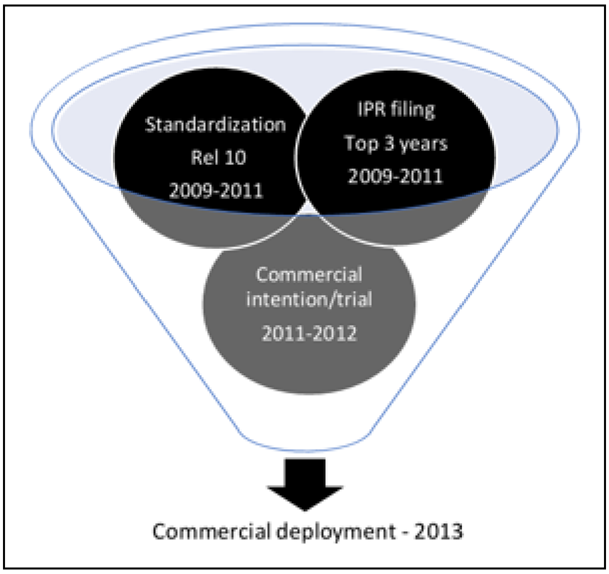
Carrier aggregation + Dual Connectivity + Cellular+WiFi (Unlicensed band)														
Declaration year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Declarations	6	0	44	83	172	164	180	151	295	306	495	Not studied	Not studied	Not studied
Release ready			Rel 8	Rel 9	Rel 10		Rel 11		Rel 12	Rel 13	Rela 14			
Release features					CA 2 DL CC		CA 2 UL CC		CA FDD-TDD joint	CA 32 CC	eLAA			
					CA max 5 CC		Multiple TAGs		Dual connectivity (DC)	LAA	eLWA			
					WLAN Offload				RALWI	LWA, LWIP	eLWIP			
									LTE-U	RCLWI				
Intention to launch														
Operator					CA	CA	CA			Beamforming	LAA, skip LTE-U	CA 5 CC		
eNB					CA									
UE					CA		CA					CA 5 CC		
Chip					CA	CA								
Other														
Test/trial of feature														
Operator						CA	CA	CA 3 CC, CA+MIMO	3 CC FDD/TDD, CA 5 CC, LAA		5G DC	ENDC		ENDC
eNB								CA+MIMO	3 CC FDD/TDD, CA 5 CC, LAA		5G DC			ENDC, 5G CA SA
UE							CA		3 CC FDD/TDD, LAA	CA 3 CC	5G DC			
Chip														5G CA SA
Other									3 CC FDD/TDD					
Commercial deployment														
Operator							CA	CA	CA 3 CC TDD, LTE-U	CA 3 CC	CA 5 CC, LWA, LAA	LAA 6 CC	ENDC	
eNB							CA	CA	CA 3 CC TDD	CA 3 CC	LWA, LAA	LAA 6 CC, LTE-U		
UE							CA	CA 3 CC			CA 5/6 CC, LWA	LTE-U		
Chip									CA 3 CC TDD		CA 6 CC, LAA	LAA 6 CC		
Other							CA Tester	CA 3 CC Tester			LWA			

Source: the author.

Basic LTE CA release 10 standardization finalized in 2011. At same year in 2011 there was already intention for commercialization by MNO, eNB vendor, UE vendor and Chipset vendor. In 2012 there was MNO trial/test towards commercial solution. In 2013 there was commercial deployment in place. Hence, commercial deployment from standardization happened within two years which shows that CA feature was expected and found necessary. Looks that vendors have been ready immediately after standardization has been finished and the standard specifications for commercial implementation have been ready.

The Figure 2 presents how basic LTE CA feature related IPR filings, Standardization and Commercialization are bound together in terms of time window according to the investigation. The 3GPP release 10 standardization time window was in 2009-2011, CA IPR filings Top 3 years were in 2009-2011, Commercialization intention/trial were 2011-2012 and Commercialization was in 2013. There can be seen their tight binding together and continuum from IPR filings and Standardization towards Commercialization. There can be seen clear correlation between those three things. One can say that LTE CA feature has been well expected. Just in curiosity, if the question would be with a feature where no commercial intentions exist the one factor (Commercial deployment) from the Figure 2 would be totally missing. One can say that IPR filing Top 3 years part in the Figure 2 reflects also high innovation activity for LTE CA, for its part.

Figure 2. From Innovation to Deployment.



Source: the author.

LTE DC release 12 standardization finalized in 2015. However, LTE DC never ended to commercial deployment phase but instead in 5G release 15 ENDC where 5G NR acting as secondary cell group appeared to commercialization intention phase in 2018 and real commercialization phase in 2019. Therefore, from the first LTE DC standardization finalization to the first commercial 5G ENDC deployment took four years. Hence, feature developed in the previous standard generation can be taken into use in the next standard generation. When development has gone towards 5G the time has been mature for NSA ENDC commercial solution in 2019 allowing small cell deployment, for example. This indicates that standardized feature is not always mature for live and commercial usage in short term but may become useful in the next standard generation later on. This may correlate somehow what the (Pohlmann, et al., 2016) mentions about previous standard technology feature utilization in the next standard technology. However, in the case of 5G ENDC there is 3GPP standard specification release 15 need for 5G but it can be thought to be more or less to LTE release 12 based.

LTE-U technology development has been ready around in 2015. In the same year 2015 the LTE-U has already been in commercialization phase. As the (Paolini, 2015) mentions the LTE-U was intended nearly for markets as China, India, South Korea and USA where the LBT is not mandatory and gives possibilities for faster commercial deployment. Around same time in 2016 the 3GPP standard release 13 finalized which brought the LAA technology available. During in 2017 the LAA was commercially deployed. In 2017 there was also indication to concentrate the LAA instead of the LTE-U. Hence, looks that the LAA took role from the LTE-U in unlicensed spectrum solution on secondary component carrier. The LWA applied rather similar timing with the LAA from standardization finalization to commercial deployment. As a conclusion, the LAA was deployed mainly in the USA with not so large scale even there were intentions and trials over the world. Hence, the deployment was not as successful as expected beforehand. Let see whether the 5G-U will be more successful on unlicensed band because there is also 5G mmWave solutions which may override the 5G-U in small cell environment.

CONCLUSIONS

There is investigated LTE CA feature deployment for commercial usage after 3GPP standardization finalization. In the first phase background literature review made for technology trends and what kind of expectations are set for CA technology. This part of literature review proved that CA is expected to be important feature from MNOs' and equipment vendors' viewpoint. Also, common understanding has been that CA is expected to be important feature. Importance was expected to lead commercial activity and bring commercial value soon when the standard is ready for implementation. The literature review and expectations served as basis when research question was set. Hence, provement needed between "hyping" and what happened in practice.

Answer to the research question relating to commercial successful started to find from public sources about MNOs' and equipment manufacturers' intentions, trials/testing and commercial deployments for LTE CA during and after standardization finalization. Measurement for success was kept how quickly those parties started to inform their actions for commercialization. After and already before standardization finalized there were immediate intentions for feature utilization. Trials appeared within one year and real commercial deployments appeared within two years from standardization finalization. The research showed that LTE CA started to be commercially successful because so complex technology deployment happened quite fast. The feature was well expected. Hence, the answer for the research question was positive and confirmed understanding what has been expected from LTE CA.

When strengthening understanding still the LTE CA feature related items were put to same time window covering Standardization, Top filing years of LTE CA feature related IPRs and Commercialization. The outcome was that those things are tightly bound and interleaved together within time axis. Therefore, correlation between them can be seen which answer to the research questions positively as well.

When thinking about other LTE CA related unlicensed band solutions as LTE-U and LAA. They were also soon in commercial deployment after their development and standardization were ready for implementation. They were successful in soon deployment context but they did not deploy worldwide as licensed band basic LTE CA.

For future works there could be investigation for detailed reasons why not LTE unlicensed band CA solutions such as LAA did not fly as expected and is there seen change when going towards 5G unlicensed band solutions. In addition, investigation for basic LTE CA from monetary success viewpoint could be topic to clarify commercial success in terms of sales worldwide.

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