Cellular inventions trigger an avalanche of activities internally and among other companies

Summary

Major innovations in cellular technologies arise largely from the substantial Research and Development (R&D) investments and inventions of relatively few companies, followed by widespread collaborations including many more in the process of standard setting.

The disproportionately large amounts of value created by those with most of the inspiration and perspiration in technology development are not reflected in simplistic and often-inflated metrics that are increasingly being used in patent-licensing rate apportionments, including by the courts in Fair, Reasonable and Non-Discriminatory (FRAND) licensing disputes. These metrics include the numbers of contributions to the standards and the numbers of patents declared-essential or cursorily judged to be essential to the standards. Thousands of negotiated and executed licensing agreements, including cross-licenses, with various terms in addition to royalty rates—all underpinned by billions of dollars paid annually over many years—much better reflect how patent-protected value is generated and exchanged.

Device manufacturers, network operators, over-the-top (OTT) service providers and end users derive enormous value from extensive and easily-available technologies in published standards from Standard-Setting Organizations (SSOs). That is evident from the huge success of cellular including extensive market entry in supply and widespread adoption.[1] With significant and increasing division of labor between the few who invent and develop Standard-Essential Patent (SEP) technologies and the many who implement these in manufactures, the formers are increasingly dependent on licensing income—based on their shares of value created and exchanged rather than on simplistic metrics such as numbers of contributions to SSOs or SEP counts—to make adequate financial returns and justify reinvestment in further technology R&D.

1 Standard-essential technology development lifecycle

New cellular and other standardized-technology innovations proceed in three overlapping and entwined stages:

1. **Conception and invention**—typically by a small number of luminaries in no more than a handful of companies
2. **Technology development**—by many experts in a relatively small number of companies
3. **Standard setting**—with numerous companies participating in technology evaluation and selection, most of whom do little or no standard-essential technology development work themselves outside the SSO.

Creating, developing and then incorporating innovative cellular communications technologies in standards is a huge endeavor that expands significantly as it proceeds. It involves increasing numbers of companies as it progresses from conception through to adoption of new technologies in Technical Specifications at 3GPP and in the standards with its seven regional partners, most significantly including the European Telecommunications Standards Institute (ETSI). Any assessment of how much value is contributed and by whom to standard-essential technologies, including 3G WCDMA or HSDPA, 4G LTE and 5G cellular, must consider the entire process including Stages 1 and

[1] Keith Mallinson, Don't Fix What Isn't Broken: The Extraordinary Record of Innovation and Success in the Cellular Industry Under Existing Licensing Practices, 23 Geo. Mason L. Rev. 967 (2016)

2, not only what is most visible and measurable in standard-setting activities, such as contributions or meeting attendance, at Stage 3.

The large R&D investments and resulting value generated in the first and second stages of innovation, identified above, are not always apparent because the work there is largely hidden from the public or might only be recognized by specialists. In contrast, the popular but simplistic use of publicly-available SSO activity metrics in Stage 3, such as counting the numbers of technical contributions to 3GPP Working Groups (WGs) as a proxy for a company's share of innovation in standards, can significantly understate the value provided by inventors and pioneers while inflating that of companies who join the bandwagon of an emerging success later on—for example, in the Study Item (SI) and Work Item (WI) phases of standard setting at 3GPP.

Most of the activities logged in the public records of 3GPP are the mere tip of the iceberg in terms of the total amount of development work undertaken, including that outside this SSO, with even more extensive other activities submerged from public view. Activities including in WGs and other meetings at 3GPP are publicly visible because "TDoc" technical contribution documents, meeting attendance records and other information are all available publicly online. But this represents only a small proportion of total effort and rather less still of technical effort or innovation, which most significantly also includes company R&D outside this SSO.

Whereas standard setting is nominally a matter of selecting the best from among various contributions, in practice the process is far more subtle, complex and multifaceted. For example, most technical contributions that are ultimately approved, are subject to multiple revisions and resubmissions before standardization is completed. Building the required consensus for technology selection among SSO participants also significantly involves consideration of non-technical issues, such as companies' business models and reputations, bilateral business agreements and nationality. Even the approval of purely technical contributions can significantly reflect these other factors in many cases. This distorts the accuracy of contribution counts as a purported indicator of patentable inventive and innovative technology developed and incorporated in the standards by one company versus another.

2 Non-linearities in apportioning rates

Neither patent counts nor contribution counts can account for significant differences among patents, and among licensors and licensees. Most declared-essential patents are not actually essential. Even adjusting counts of these with third-party standard-essentiality assessments is problematic because it introduces additional inaccuracies including bias.[2] SEPs are not all of equal value. The same proviso applies to judged-essential patents and to SSO contributions. Bargaining strength is not proportional to any of these counts and depends on other significant factors including R&D pipeline and technology roadmap, position or absence thereof in downstream product markets.

Many patent-licenses established bilaterally with numerous licensees and underpinned by billions of dollars in payments over many years reflect all these complexities and subtleties. Formulae used to diagnose existing licenses and apportion royalty rates elsewhere simplistically misrepresent these dynamics.

Nevertheless, both parties in the TCL v. Ericsson SEP royalty rate-setting dispute agreed to use a simple algebraic formula with inverse proportionality (i.e. using only +, −, x and ÷) to "unpack"

[2] http://www.ip.finance/2017/05/do-not-count-on-accuracy-in-third-party.html

various existing cross-licenses in the derivation of one-way licensing rates.[3] Variables include licensed sales, royalty rates, relative patent strength and balancing payments.

Presiding Judge Selna expressed "some reservations" about top-down royalty-rate apportionment methodology based on patent-counting proportionality in this litigation; but he used it there, regardless, as his primary means of determining FRAND rates in his declaratory judgement.[4]

3 Outstanding technology value in cellular communications standards

In a cellular marketplace worth trillions of dollars, with value and growth significantly driven by recent technologies such as LTE Advanced, LTE-LAA and upcoming 5G, is it important to identify where and how much value is generated and exchanged in SEP technologies. Innovators' rewards should be commensurate with that—as exemplified in numerous executed licenses— not based on simplistic counts of contributions to SSOs or patents.

The example of taking cellular technology into unlicensed spectrum including LTE-LAA is a pertinent case study illustrated how and where value is created in standard development because this major innovation significantly involved various regulatory and commercial matters as well as issues concerning the incorporation of already-standardized and new technologies.

Technical specifications and standards are published openly[5] so that new technology features can be rapidly and widely exploited in products and services to the benefit of thousands of companies and billions of consumers. For example, the LTE standard was completed with 3GPP Release 8 in early 2009. The first commercial services launched later that year. LTE was subsequently improved, under the umbrella naming of LTE Advanced and LTE Advanced Pro, with additional features including Carrier Aggregation (CA) in 3GPP Release 10 and Licensed-Assisted Access (LAA) in Release 13. There were 1.65 billion LTE chips shipped in 2017[6] and 1.75 billion LTE subscriber connections by yearend 2017,[7] accounting globally for 67 percent of all shipments and 22 percent of all connections. There were 9,544 distinct LTE user device models on the market from 570 manufacturers in 2017.[8] By any reasonable reckoning, this current-generation standard including numerous improvements since its commercial inception only nine years ago, accounts for a substantial proportion of the value in the cellular ecosystem generating annual revenues of around $1.5 trillion including chips, devices, network equipment and operator services.

Cellular is the main communications platform upon which OTT tech titans including those in social media, content streaming and ecommerce (e.g. Facebook and YouTube and Amazon, respectively)

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[3] TCL v. Ericsson Decision, page 62: https://www.essentialpatentblog.com/wp-content/uploads/sites/64/2018/01/2017.12.21-1802-Court-Memo-of-Facts-and-Law-PUBLIC-CORRECTED.pdf

[4] TCL v. Ericsson Decision, page 50. This is a flawed methodology and the judge also made significant mistakes in its application: http://www.ip.finance/2018/04/unreasonably-low-royalties-in-top-down.html

[5] Technical specifications are published for download free of charge, but this is does not mean free of charge for their implementation in devices. Instead, ETSI IPR policy (Section 3.2) states "IPR holders whether members of ETSI and their AFFILIATES or third parties, should be adequately and fairly rewarded for the use of their IPRs in the implementation of STANDARDS and TECHNICAL SPECIFICATIONS." http://www.etsi.org/images/files/IPR/etsi-ipr-policy.pdf

[6] Strategy Analytics Baseband Market Share Tracker, March 2018. LTE chip shipment figures are approximately the same as total numbers of LTE-capable handsets and other devices shipped.

[7] GSMA Intelligence, https://www.gsmaintelligence.com/

[8] Status of the LTE Ecosystem, GSM Suppliers Organisation, 20th November 2017 https://gsacom.com/paper/status-lte-ecosystem/

are thriving with rapid growth.[9] Cellular is also a major source of advertising revenue and transaction fees for web search and ecommerce platforms including Google and Amazon, respectively.

Many other OTT players based outside the US including in China are also growing rapidly on the back of mobile networks and operator services. Baidu dominates China's search market, with 665 million users in mobile, as Alphabet's Google dominates elsewhere.[10] Tencent leads in gaming and social networking with 1 billion users for its WeChat service. Alibaba leads in ecommerce which is particularly popular over smartphones in China. For example, on Singles Day in 2017, Alibaba and JD.com sold merchandise with a gross value of $44.7 billion— that is several times more than purchased with smartphones over the Black Friday and Cyber Monday period in the US. 90 percent of all Alibaba merchandise sales are purchased on smartphones.[11]

4 Avalanche effect with inventions triggering work for many others

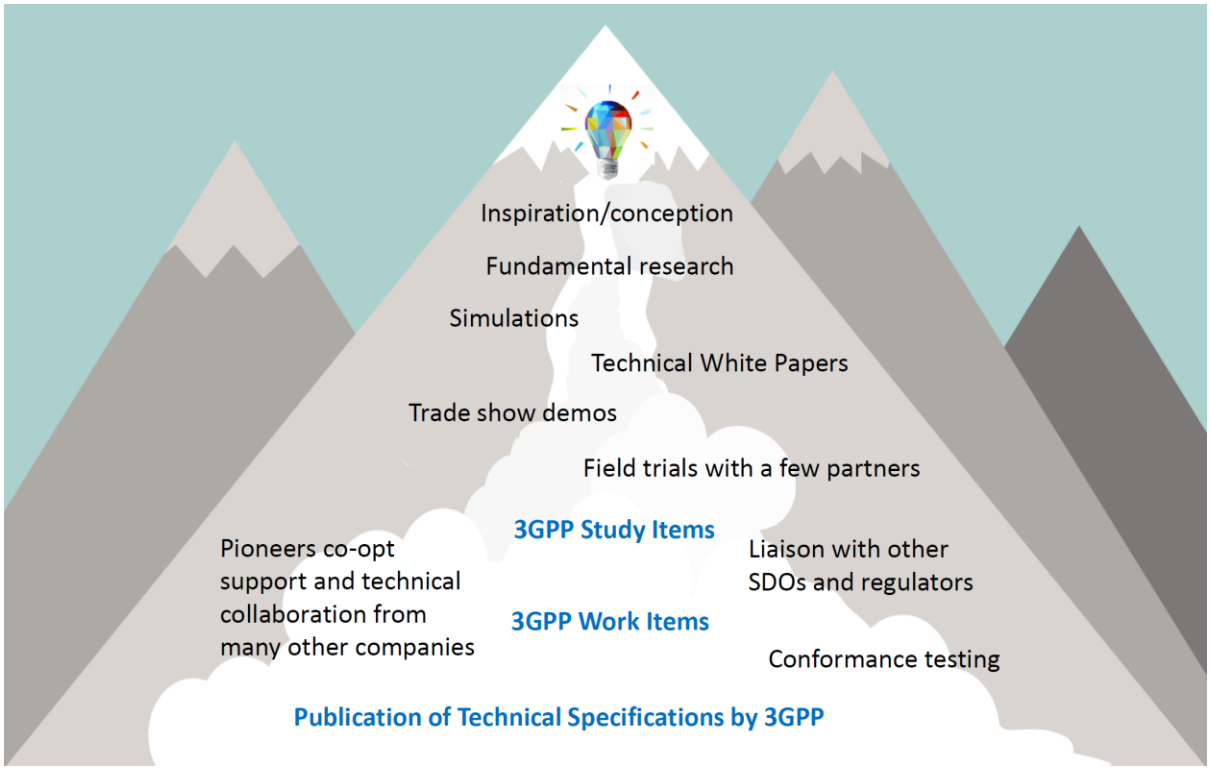
The enormous advances in cellular communications technologies in 3G, 4G and upcoming 5G standards are largely the result of the initial inventive and innovative endeavors by a small number of highly-focused experts, followed by widespread participation in their employer's firms and among others. There is then an avalanche of activity in the development of any technology for standardization in an SSO such as in cellular at 3GPP, as depicted in Exhibit 1. The inspirational inventions that are made by a few, some of which include patentable intellectual property, trigger more extensive R&D activity within their firms and some activity among many others, as the latter collaborate and compete with the former. Developments progress from conception and various associated internal activities to more public presentations including the publication of technical papers, patenting, public demonstrations, field trials and technical contributions for standardization by SSOs. Pioneers must also obtain commitments for various external resources such as SSO time and spectrum allocations. They also need commitments to manufacture from network equipment, chip and device vendors; and to deploy in networks by service providers. In return, the latter demand ongoing commitments from technology developers including R&D and trials, for example, to ensure interoperability, backward compatibility and minimal unwanted radio interference.

[9] https://www.rcrwireless.com/20170920/opinion/analyst-angle-5g-investment-threatened-by-tech-titans-snatching-financial-growth-from-mobile-operators-tag10#prettyPhoto

[10] China Releases a Tech Dragon: the BAT, 23 May, 2018, https://techonomy.com/2018/05/china-releases-tech-dragon-bat/

[11] E-commerce – Look East, Radio Free Mobile, 27 November, 2017, http://www.radiofreemobile.com/2017/11/27/e-commerce-look-east/

Exhibit 1: Inventor inspiration and technology conception triggers an avalanche of activities



Much of the most patently-valuable innovation in developing new technologies occurs before any significant standard-setting work has commenced. This includes fundamental research, some of which is carried out confidentially in company R&D labs. Some of the most seminal and valuable patent applications are made at this stage.

Innovations are typically based on substantial research and development efforts, including significant inspiration and extensive perspiration[12] in prototyping, simulations and testing in company laboratories. In some cases, this R&D work starts many years before any standard-setting and is largely outside SSO activities including Working Group meetings.

R&D of technologies that may become standard essential, for use by all implementers of the standards, continues throughout the standardization process and may expand to include some additional companies; but, typically, only small numbers of companies invent or do the technical development work on any individual standard-essential technology. However, others do contribute in different ways; by helping evaluate, select and in providing support for technologies that are ultimately chosen for standardization.

Many innovations and innovators build upon a limited selection of foundational inventions already developed by the same individuals and companies. Even though LTE was an entirely new standard with 3GPP Release 8 in 2009, many of the core technologies upon which it and its improvements are based—such as carrier aggregation with LTE Advanced in Release 10 in 2011—were adopted from elsewhere in much earlier technology developments from among a small number of inventors and innovators. Carrier aggregation was added to HSDPA, also in Release 8, after it had been first implemented in CDMA2000 EV-DO Rev B, which was standardized in 2006. This highlights the high importance and value of the foundational inventions and early innovative work versus activities in

[12] https://www.brainyquote.com/quotes/thomas_a_edison_109928

SSOs that are more prominent, easier to quantify and tend to occur later in the technology development cycle.

5 What goes on in SSOs

Standard setting is achieved with a lot of detailed collaborative evaluation work and driven by consensus-based decision making. The final stage in the standard-essential technology development process of setting the technical specifications and standards involves many people and companies who attend WG meetings, some of whom submit technical contributions for evaluation. There is a high attrition rate for technologies proposed for inclusion in the standards. Only a minority of contributions are approved for inclusion in the standards.[13] Completion of fully-fledged technical specifications on which standards are built requires significant work from many to evaluate and select the most performant technologies for inclusion. Many companies tend to get involved: however, to greatly varying extents. While some may devote many thousands of hours in the development of certain specific contributions, many others will do little or no more than have their names added to contributions to which they are willing to support. Coaxing and horse-trading among SSO members to build support for the inclusion of a particular technology is inevitable and commonplace at 3GPP.

Technologies are not simply imported on a pre-assembled basis and rubber stamped at 3GPP, they are reconstructed element-by-element and thoroughly verified before approval. With selection of new technologies hardly ever put to a formal vote, decision-making involves extensive consensus building in selection of technologies for standardization from among numerous proposals and with a wide variety of many different technical and commercial interests.

My analysis of standard setting at 3GPP in this article focuses on work at the Technical Specifications Group (TSG) and WG levels, particularly in the Radio Access Network (RAN) area, including meetings and workshops.

It is not the purpose of this article to explain how SSOs operate in detail. Three short articles by Signals Research, that are largely not very technically oriented, provide an excellent primer for those who are interested in but not yet familiar with the workings of 3GPP and the standards it develops.[14]

6 Counting 3GPP activity levels

Standard setting attracts a lot of public attention because it is the most publicly visible part of the cellular innovation process; even though it largely follows behind invention and technology development. Standard setting is also easy to track with all sorts of information freely available online and this is newsworthy with so many participants and different commercial interests in SSOs.

Research on attendance records of all the 3GPP WG meetings between the years 2005 and 2013 reveals the substantial amount of time and effort that has been devoted by 3GPP participants to the

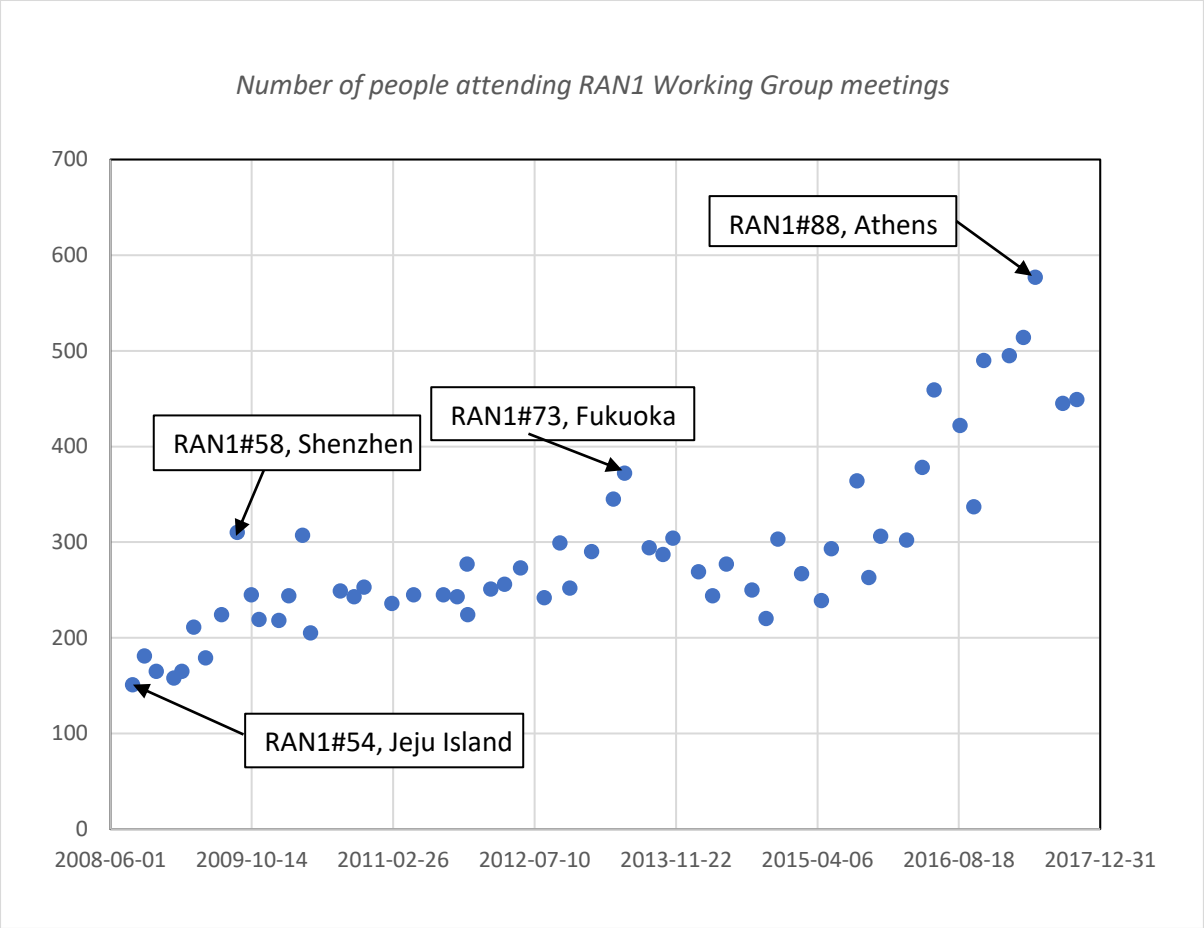
[13] According to a study of contributions to 3GPP for 3G to LTE Release 12 by Signals Research published in 2015, only 17 percent of submissions were approved, http://signalsresearch.com/issue/the-essentials-of-intellectual-property-from-3g-to-lte-release-12-5/

[14] 3GPP Fun Facts Part 1, Signals Research Group, 12th October 2017
https://www.rcrwireless.com/20171012/analyst-angle/3gpp-fun-facts-part-1-analyst-angle
3GPP Fun Facts Part 2, Signals Research Group, 31st October 2017
https://www.rcrwireless.com/20171031/opinion/analyst-angle-3gpp-fun-facts-part-2
3GPP Fun Facts Part 2, Signals Research Group, 19th December 2017
https://www.rcrwireless.com/20171219/analyst-angle/3gpp-fun-facts-part-3

development of 3G and 4G standards.[15] A total of 3,452,040 man-hours were spent in 825 WG meetings.

Activity levels in 3GPP have significantly risen since the inception of LTE in 3GPP standard Release 8, as finalized in 2009, and particularly since 2014 in preparation for upcoming 5G, which commences with Releases 15 and 16. This is illustrated in Exhibit 2 by the number of people attending RAN1 WG meetings, for example, where most patented technologies relating to the cellular radio air interface, are incorporated in the standards. Some companies and even divisions of the same company send several people to the same meeting.

Exhibit 2: Working Group meeting attendance has surged at 3GPP RAN1 since 2014



Source: WiseHarbor using 3GPP meeting attendance records

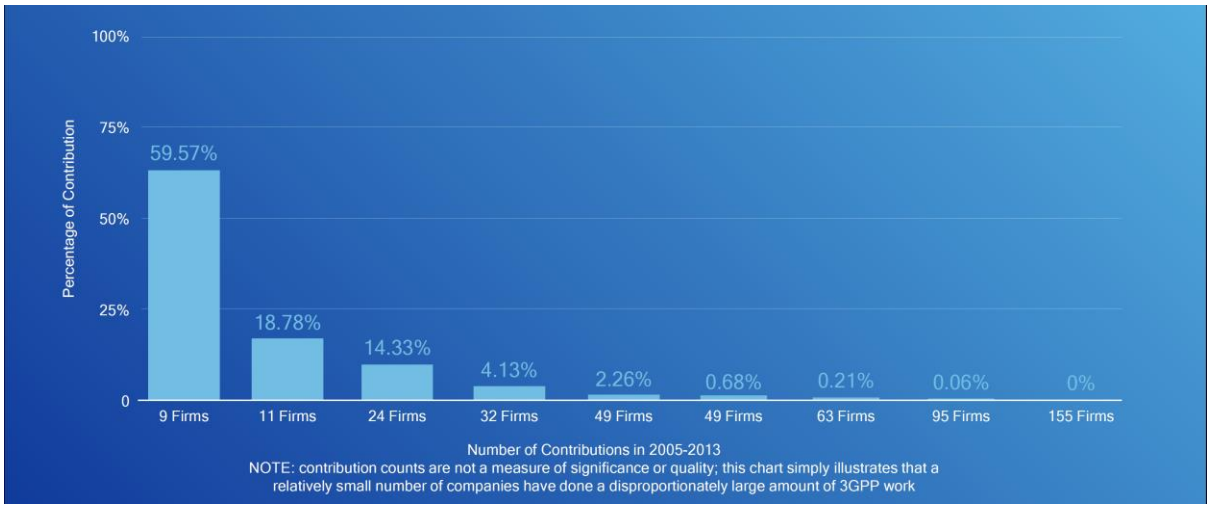
Research also reveals that a few highly-active firms are largely responsible for most technical contributions at 3GPP, as shown in Exhibit 3. For example, the top 2 percent (9) of firms are responsible for submitting 60 percent of all contributions.[16] Furthermore, approximately one-third of all participating firms (33 percent, 161) have not submitted a single contribution to 3GPP. Some contributions have several or many company names listed as contributors, even where virtually all

[15] Unpacking 3GPP Standards, by Baron, Gupta and Roberts, 24th March 2015 https://pdfs.semanticscholar.org/bb7a/902cdedbc5fb97b039372d0c7541c696e539.pdf

[16] Unpacking 3GPP Standards, by Baron, Gupta and Roberts, 24th March 2015 https://pdfs.semanticscholar.org/bb7a/902cdedbc5fb97b039372d0c7541c696e539.pdf

the underlying work has been carried out by a much smaller number of companies or only one company.

Exhibit 3: Very few active contributors to 3GPP Working Groups

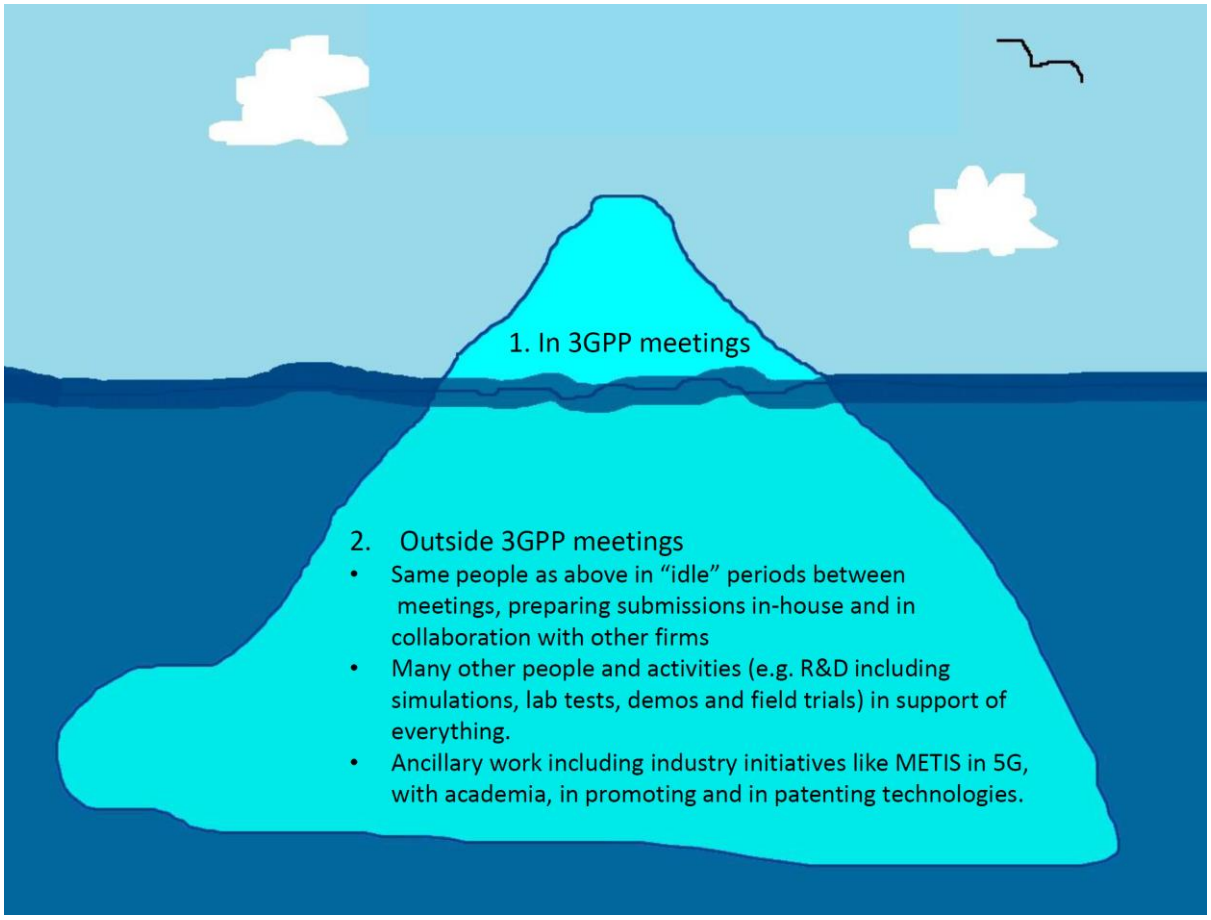


While this skew is substantial, it nevertheless significantly understates how even more polarized standard-essential technology investments, developments and innovative value created is among 3GPP members, due to the avalanche effect from a few leading innovators among those top contributors, as already described, and with the iceberg phenomenon with most work occurring outside the SSO, as discussed below.

7 Iceberg phenomenon with prominent SSO activities and other work largely hidden

Most of the activities in the public records of 3GPP are the mere tip of the iceberg in terms of the total amount of development work undertaken including that outside this SSO, with even more extensive other activities submerged from public view. Activities including in WGs and other meetings at 3GPP is publicly visible because “TDoc” technical contribution documents, meeting attendance records and other information are all available publicly online. But this represents only a small proportion of total effort and rather less still of technical effort or innovation, which most significantly also includes company R&D outside this SSO, as illustrated in Exhibit 4, and that forms the essential basis of contributions to SSO WGs.

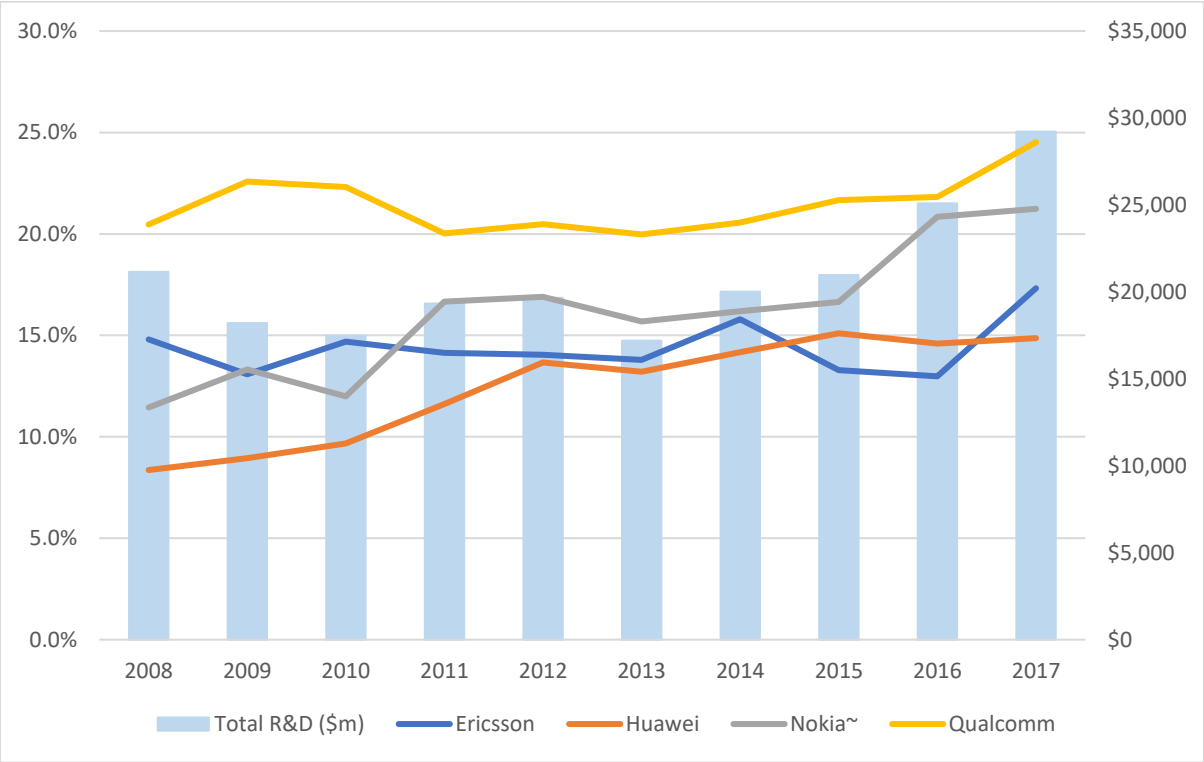
Exhibit 4: SSO work at 3GPP is the tip of the iceberg versus total R&D required for standards development[17]



Companies developing cellular technologies are typically spending far more time and money on R&D outside of SSO meetings than SSO participation figures indicate. At an assumed cost of $100 per hour in an eight-hour day, the 3,452,040 man-hours spent by all participants in 3GPP WG meetings between 2005 and 2013 is equivalent to $38 million dollars per year. That may seem like a lot of money, but it is three orders of magnitude smaller than (i.e. less than 0.2 percent of) the total R&D spending of $30 billion in 2017 for just a handful of the leading cellular industry innovators identified below. Even if one allocates additional time and costs for travel and preparation of documents contributed to the WGs, the total costs would still pale in comparison to total R&D expenditures, as indicated in Exhibit 5.

[17] The METIS project developed a 5G system concept consisting of three generic 5G services: extreme mobile broadband, massive machine-type communication, and ultra-reliable machine-type communications, https://ieeexplore.ieee.org/document/7786123/

Exhibit 5: Total R&D investment and R&D as a percentage of sales for top cellular technology developers



Figures are for years ending 31st December except for Qualcomm with its 30th September yearend.
~Includes Alcatel Lucent figures for periods prior to its merger with Nokia.
Source: WiseHarbor; using figures from companies' annual reports.

Cellular R&D investments are large and have increased significantly in recent years, including by Nokia and Ericsson that have divested their handset businesses and by Qualcomm whose only product business is in chips. With reducing scope to monetize fruits of R&D in product businesses, patent licensing is becoming increasingly important to justify R&D investments. These companies are significantly and increasingly investing in development of standard-essential technologies for exploitation by manufacturers of standard-compliant equipment; on FRAND-licensing terms, as well as in R&D for their own remaining products (e.g. network equipment by Ericsson, Huawei and Nokia).

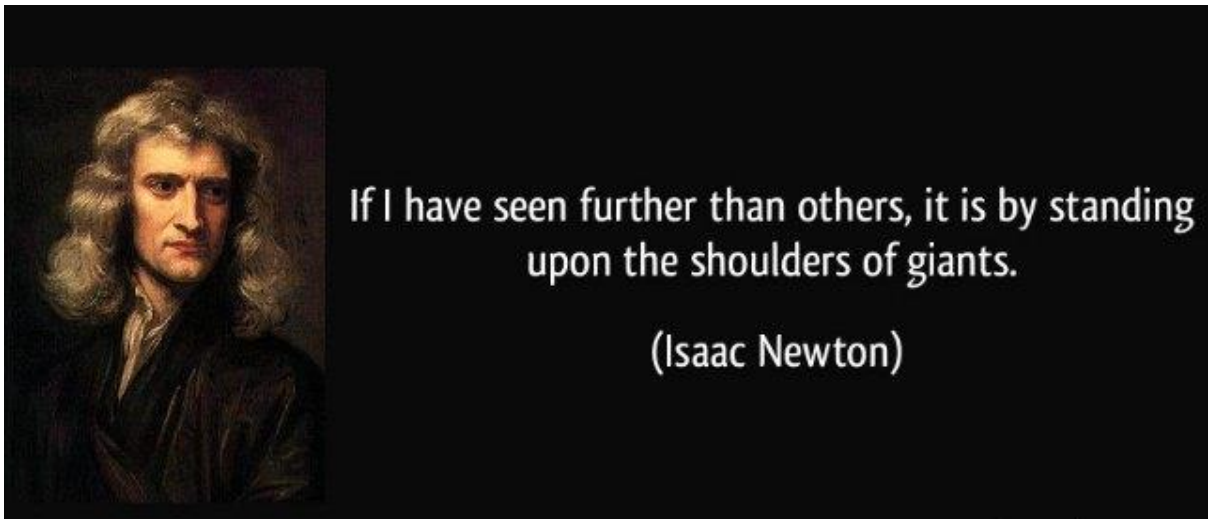
On the other hand, the vast majority of companies attend SSO meetings to monitor developments and express opinion or to influence decision making, while doing very little, if anything, in actual technology development work themselves outside the meetings.

The broad and increasing participation in standards setting with TDoc contributions and meeting attendance reflects many factors, including widening interest across many different industries with the Internet of Things (IoT), as communications capabilities are increasingly included in a much wider range of devices than mobile phones. Many of these individuals participate in the latter stages of the standardization process on behalf of companies who seek to innovate with applications and services outside of the standards, while using 4G and 5G cellular communications as a platform, rather than participating as innovators in standard-essential cellular technologies themselves.

8 Shoulders of giants

Many inspirational and highly innovative new technologies are fundamentally dependent upon and built significantly upon existing technologies. Sir Isaac Newton saw things similarly for his scientific discoveries, as shown in Exhibit 6. Major cellular technology advances are typically characterized in terms of generational changes, such as the switch from analog 1G to digital 2G, and from code-based 3G (e.g. CDMA2000 and WCDMA) to OFDMA-based 4G technologies. There are, however, many very significant technology developments that are somewhat independent of and straddle these generational changes. This applies to technologies in the generation-defining radio air-interfaces, and elsewhere such as in the core network that is significantly independent of the specific type of radio access technologies employed, while depending on the latter to provide adequate performance and capacity.

Exhibit 6: Cellular innovators were not the first to build upon previous successes



The value in cellular technologies is cumulative. More than 200,000 patents in tens of thousands of patent families[18] have been declared possibly essential to 3GPP's standards by more than 200 companies. A small minority of these companies own the bulk of these patents. While it is impossible to accurately determine company shares of patents actually standard essential, or of innovative value in 3GPP standards, by counting patents or contributions to 3GPP,[19] the overall value is clearly substantial in this large industry sector that keeps demonstrating such rapid technological advances with widespread consumer benefits and popularity.[20]

9 LTE-LAA – a case study in invention, development and collaboration

9.1 Tapping additional spectrum

Radio spectrum is the life-blood of wireless networks. Licensed spectrum has been cellular operators' first choice because it provides reliability, security of investment, and predictable performance. However, it is a scare and costly resource. With traffic demand increasing by a factor

[18] A patent family is a set of patents taken in various countries to protect a single invention.
[19] http://www.ip.finance/2017/05/do-not-count-on-accuracy-in-third-party.html
[20] Keith Mallinson, Don't Fix What Isn't Broken: The Extraordinary Record of Innovation and Success in the Cellular Industry Under Existing Licensing Practices, 23 Geo. Mason L. Rev. 967 (2016)

of 1,000 over 15 years to 2025,[21] the industry has been eager to expand usable spectrum resources by also taking cellular technologies into spectrum bands that do not provide the exclusive rights of conventional licensed spectrum.

Technology and commercial developments to use alternatives to conventional paired spectrum[22] in licensed frequency bands were clearly occurring by 2011. For example, AT&T acquired some unpaired spectrum that year with the intention of deploying that as a supplemental downlink.[23]

Possibilities also included new paradigms such as authorized/licensed shared access (ASA/LSA) providing intermittent spectrum availability in certain locations, as well as the use of unlicensed frequency bands. ASA was demonstrated by Nokia Siemens Networks and Qualcomm at the Mobile World Congress in February 2013.[24]

9.2 A pertinent case study

The example of taking cellular technology into unlicensed spectrum with LTE-LAA makes a great case study in standards development because this major innovation significantly involved various regulatory and commercial matters as well as issues concerning already-standardized and new technologies. Everything must be resolved for a new technology—no matter how inventive —to be standardized. This could only occur with widespread support including consensus in 3GPP.

The unlicensed frequency bands have traditionally been unsuitable for use with access technologies designed to provide wide-area coverage, such as cellular, which have only operated in licensed frequencies with exclusive use. However, for the first time, LTE features such as CA, together with some additional technology developments, have made it possible to operate LTE in unlicensed bands as well.

Descriptions of the technological and commercial developments that have created LTE-LAA are provided in the Appendix.

The rest of this article is focused on describing the avalanche of activity at 3GPP triggered by the inspiration that it was desirable and possible to take LTE into unlicensed spectrum; and facilitated by the pre-exiting CA technologies standardized in LTE since Release 10 and in 3G standards previously. Numerous companies added their names to technical contributions in the standard-setting process for LTE-LAA, while the underlying CA techniques, including those developed specifically for unlicensed spectrum, had already been developed and implemented in previous standards releases at 3GPP or another SSO; or were being developed outside of 3GPP WGs in company labs, demos and trials before standardization there or elsewhere.

[21] https://www.fiercewireless.com/europe/mallinson-duct-and-pole-access-essential-for-1000-times-growth-5g

[22] Spectrum is paired so that uplink and downlink can each have their own, separate, frequency channels that can be used simultaneously. In contrast, uplink and downlink take it in turns to share the same frequency channel in unpaired spectrum.

[23] https://www.fiercewireless.com/wireless/fcc-approves-at-t-s-1-93b-purchase-qualcomm-s-700-mhz-spectrum

[24] http://wireless.fcc.gov/workshop/PANEL%201-2%20Prakash%20Moorut%20-%20Nokia%20Siemens.pdf

9.3 Technology development milestones and standard-setting events for LTE in unlicensed

It might seem that putting LTE into unlicensed spectrum only entailed recently-developed technology because LTE in unlicensed spectrum was not even proposed as an Study Item until the TSG RAN #63 plenary meeting in March 2014. It was first standardized at 3GPP, in the form of LAA, in Release 13 (March 2016). However, the key foundations for this innovation started to be laid a couple of decades earlier. As indicated in the Appendix, the innovative technological foundations for LAA with multi-carrier in CDMA2000 EV-DO, followed by CA in WCDMA/HSPA and then LTE were developed over many years from the early 2000s.

Until late 2013, public discussion on combining licensed and unlicensed usage focused on aggregating different technology links with LTE in licensed spectrum and Wi-Fi in unlicensed spectrum, as opposed to aggregating the two types of spectrum for use by only one technology. For example, this kind of link aggregation was described in detail in a 2013 presentation by Fujitsu.[25]

The possibility of using LTE in unlicensed spectrum was first discussed publicly and in 3GPP from December 2013. This included a joint presentation by Ericsson and Qualcomm at the TSG RAN #62 meeting in Busan, and with Qualcomm publishing a detailed White Paper on the topic that month.[26]

Exhibit 7 lists the other contributions with “unlicensed” in their titles at this meeting. No contribution titles included the term “LAA” until later meetings.

[25] http://www.fujitsu.com/downloads/SVC/fla/research/Adaptive-Small-Cell-Access-of-Licensed-and-Unlicensed-Bands.pdf

[26] https://www.qualcomm.com/media/documents/files/white-paper-extending-lte-advanced-to-unlicensed-spectrum.pdf

Exhibit 7: Contributions for RAN Plenary #62 in Busan, December 2013[27]

	Tdoc	Title	Source
1	RP-131635	Introducing LTE in unlicensed spectrum	Qualcomm, Ericsson
2	RP-131701	Drivers, Benefits and Challenges for LTE in Unlicensed Spectrum	AT&T
3	RP-131680	New WID: New Band for LTE deployment as Supplemental Downlink in unlicensed 5.8 GHz in USA	Verizon
4	RP-131749	On LTE in Unlicensed Spectrum	Cisco
5	RP-131723	Discussion paper on Unlicensed Spectrum Integration to IMT systems	Huawei, CMCC, CATR, CATT
6	RP-131788	New Study Item proposal: Study on LTE Evolution for Unlicensed Spectrum Deployments	Ericsson
7	RP-132008	On LTE in Unlicensed Spectrum	Broadcom
8	RP-132079	Way forward on LTE operation in unlicensed bands	ORANGE, Deutsche Telekom, Vodafone Group, Telefónica, AT&T, Sprint, SouthernLINC, US Cellular, DISH Network, Softbank, eAccess, KT corp., LG Uplus
9	RP-132085	New SI: Study on Unlicensed Spectrum Integration to LTE	CMCC

Most of the companies supporting these contributions are operators, with interests primarily as customers for the prospective new technology rather than as technology developers or manufacturers. Operators hold a lot of sway in determining which technologies are selected for standardization in cellular, but rarely do much of the standard-essential technology development work and tend to hold only small proportions of SEPs, by any reckoning.

Whereas the numbers of company names involved in the topic of LTE in unlicensed spectrum had begun to increase significantly, there were still far fewer than would subsequently participate in upcoming 3GPP workshops, plenaries and Working Group meetings.

The Busan meeting was soon followed by an impromptu workshop on LTE in unlicensed bands hosted by CMCC, Ericsson, Huawei, Qualcomm and Verizon in Paris, January 2014. Presentations were also submitted for that event by China Mobile (CMCC), Sprint, DoCoMo, Hitachi, Samsung, Nokia Siemens Networks, Broadcom, IAESI, Alcatel-Lucent, Sony, CATT, Intel, LG, ZTE, Nokia and AT&T— 20 companies in all.[28] This was not a 3GPP event and so this, including contributions to it, are not in 3GPP's meeting records apart from a meeting report contributed to 3GPP TSG RAN Meeting #63 by the five host companies in March 2014.[29]

[27] Where contributions were revised, earlier versions have been omitted
http://www.3gpp.org/DynaReport/TDocExMtg--RP-62--29573.htm
[28] https://www.dropbox.com/sh/8xjlm6gcccgnuwd/QovKbhhX5T
[29] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_63/docs/RP-140060.zip

The initial proposal for a Study Item on LAA was submitted by CMCC, Verizon and others at TSG RAN#63 in Fukuoka, March 2014.[30] Excluding subsidiaries and affiliated companies, seven vendors and six operators are named on 3GPP's web site as contributors on the topic of LTE in unlicensed spectrum at that meeting, as indicated in Exhibit 8.

Exhibit 8: Contributions on unlicensed at TSG RAN #63 in Fukuoka, March 2014[31]

Tdoc	Title	Source	Remarks
RP-140060	Workshop Summary: LTE in Unlicensed Spectrum	Huawei	-
RP-140054	Review of the global regulatory situation applicable to LTE-Unlicensed	Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, Ericsson, Huawei, HiSilicon, LG Electronics, Nokia, NSN, Qualcomm	-
RP-140057	On the primacy of licensed spectrum in relation to the proposal of using LTE for a licensed-assisted access to unlicensed spectrum	Qualcomm & others	-
RP-140214	Motivation of the New SI Proposal: Study on Licensed-Assisted Access using LTE	Huawei, CMCC, Ericsson, Qualcomm, Verizon	
RP-140245	Way forward on LTE operation in unlicensed bands	ORANGE, AT&T, Telefonica, US Cellular and others	-
RP-140259	New Study Item Proposal: Study on Licensed-Assisted Access using LTE	Ericsson, Qualcomm, Huawei	-
RP-140260	Study on Licensed-Assisted Access using LTE - Motivation	Ericsson, Qualcomm, Huawei	
RP-140469	Way Forward on Licensed-Assisted Access using LTE	Huawei, Qualcomm, Ericsson, CMCC, Verizon	
RP-140481	New SID Proposal: Study on Licensed-Assisted Access using LTE	CMCC, Verizon	revision of RP-140240; new SI for LTE; leading WG: RAN; WI code not yet allocated as proposal with same name in RP-140259; similar SI proposal was postponed at RAN #62 in RP-132085
RP-140487	Way forward on LTE unlicensed	Orange	0

[30] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_63/docs/RP-140481.zip

[31] Where an earlier contribution was revised, the line item for the earlier version has been omitted

There were only two contributions on LTE in unlicensed spectrum at RAN #64, as shown in Exhibit 9.

Exhibit 9: Only two contributions on unlicensed at TSG RAN #64 in Sophia Antipolis, June 2014

Document Name	Title	Source
RP-140740	New SI proposal: LTE in Unlicensed Spectrum in 5.8GHz	China Unicom
RP-140808	Review of Regulatory Requirements for Unlicensed Spectrum	Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, Ericsson, Huawei, HiSilicon, IAESI, LG, Nokia, NSN, Qualcomm, NTT Docomo

However, collocated with the above was RAN Workshop 14 (RWS-14). This was a significant meeting with 27 contributions from 33 companies, as indicated in Exhibit 10.[32] Unmentioned previously, LAA terminology also began to be appear in the titles to a couple of contributions to this event, and increasingly so subsequently.

[32] https://portal.etsi.org/webapp/meetingDocuments/ViewDocumentList.asp?MTG_Id=31471

Exhibit 10: RWS-14 contributions and contributors in Sophia Antipolis, June 2014[33]

Document	Title	Source
RWS-140002	LTE in Unlicensed Spectrum: European Regulation and Co-existence Considerations	Nokia Corporation
RWS-140003	AT&T Perspectives on LTE in unlicensed spectrum	AT&T
RWS-140004	CableLabs perspectives on LTE-U coexistence with Wi-Fi and operational modes for LTE-U	Cable Television Laboratories
RWS-140005	Scenarios, spectrum considerations and preliminary assessment results of U-LTE	HiSilicon
RWS-140006	A look at the requirements for LTE in the Unlicensed Bands	InterDigital Communications
RWS-140007	Deutsche Telekom / T-Mobile USA view on LTE Carrier Aggregation with unlicensed spectrum	Deutsche Telekom, T-Mobile USA
RWS-140008	Extending the benefits of LTE to unlicensed spectrum	Qualcomm
RWS-140009	Consideration of Unlicensed LTE Spectrum in China	China Unicom
RWS-140010	Requirements and Proposed Coexistence Topics for the LTE-U Study	Sony
RWS-140011	An operator view on LTE in unlicensed spectrum	TeliaSonera
RWS-140012	LTE Operation in Unlicensed Spectrum	Texas Instruments
RWS-140013	Specifications of LTE Unlicensed	Alcatel-Lucent, Alcatel-Lucent Shanghai Bell
RWS-140014	On the Standardisation of LTE on unlicensed spectrum	Alcatel-Lucent, Alcatel-Lucent Shanghai Bell
RWS-140015	Review of Regulatory Requirements for Unlicensed Spectrum	Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, Ericsson, Huawei, HiSilicon, IAESI, LG, Nokia, NSN, Qualcomm, NTT Docomo
RWS-140016	Performance evaluation of LTE in unlicensed spectrum	Samsung
RWS-140017	Hitachi Perspectives on LTE-U	Hitachi, Ltd
RWS-140018	LTE in Unlicensed Spectrum	Intel Corporation
RWS-140019	Considerations on LTE-U in Rel-13	CATT
RWS-140020	Use Cases & Scenarios for Licensed Assisted Access	Verizon, CMCC, Huawei, Ericsson
RWS-140021	Discussion on LTE in Unlicensed Spectrum	ZTE
RWS-140022	Discussion on Licensed-Assisted LTE	Broadcom Corporation
RWS-140023	KT Perspective on LTE in unlicensed spectrum	KT
RWS-140024	KDDI Proposals on Technology Requirement Clarification	KDDI Corporation
RWS-140025	Co-existence considerations for LTE-U	Cisco
RWS-140026	Views on LAA for Unlicensed Spectrum - Scenarios and Initial Evaluation Results	NTT DOCOMO
RWS-140027	On integration of unlicensed spectrum	BlackBerry UK Ltd.
RWS-140028	Consideration of LTE in Unlicensed Spectrum	Fujitsu

[33] Some contributions to this and other meetings argued against proposals for LTE-in-unlicensed spectrum.

Work accelerated as new Study Items were proposed by Ericsson, Huawei and Alcatel-Lucent at TSG RAN #65 in September 2014 and TSG RAN #66 in December 2014.[34] Ericsson, Huawei, Qualcomm and Alcatel-Lucent proposed a new Work Item at TSG RAN#68 in June 2015.[35]

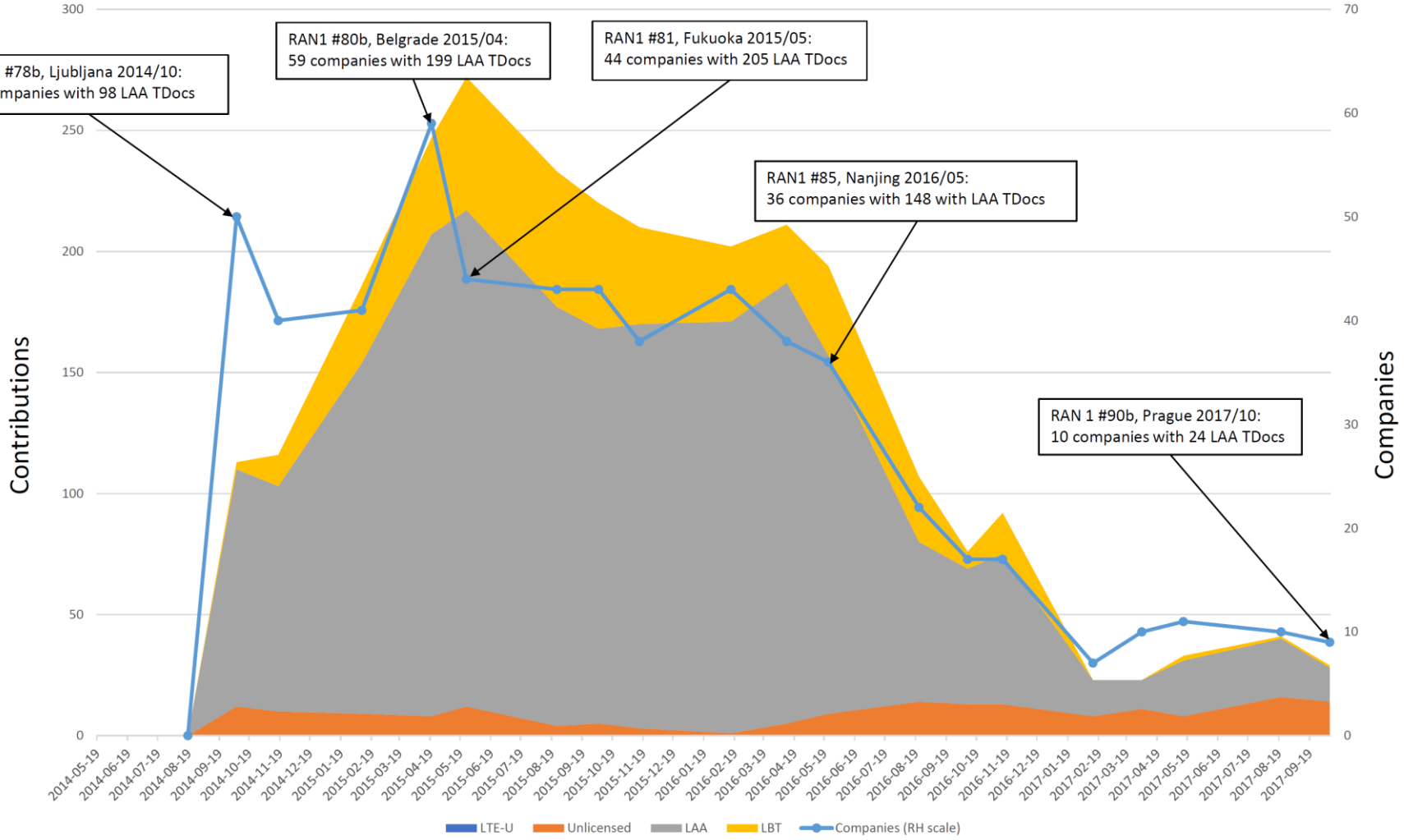
From mid 2014, activities in 3GPP on this topic expanded beyond the TSG, its plenary meetings and the workshop, as indicated above, to among 3GPP's 16 Working Groups, particularly including some of RAN's six WGs. Following Study Items, WGs proceeded most significantly with the Work Item phase.

To illustrate how the above generates WG activity, Exhibit 11 charts WG activity levels relating to LTE in unlicensed spectrum toward standard setting in RAN1 with numerous new and amended Technical Specifications. The RAN1 WG focuses on the radio physical layer (Layer 1). It is the WG where most activity occurs and where patented intellectual property most commonly reads on the Technical Specifications (TSs). In other words, innovative technologies, particularly those relating to new radio innovations like CA and unlicensed use, feed into RAN1 meetings, evaluations, decision making and TS drafting. Nevertheless, there was also significant work liaising among and within other WGs in standard setting for LAA.

[34] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_65/Docs/RP-141646.zip and http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_66/Docs/RP-141817.zip

[35] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_68/Info_for_workplan/new_approved_WI_47/RAN1_3/RP-151045.zip

Exhibit 11: Numbers of contributions with TDoc titles including "unlicensed", "LAA" or "LBT" to RAN1 meetings and companies contributing those[36]



[36] Where more than one search term appears in the title, the contribution is only counted once with LAA trumping unlicensed and LBT trumping LAA.

Following the very first Working Group contributions on this topic, to RAN1 #78b in October 2014, WG activity peaked at RAN1 meetings in April and May 2015 with 59 contributing companies and 199 contributions with "LAA" in the TDoc title. Standard-setting activity there continued at more than two-thirds that level for another year before subsiding substantially, followed by an uptick in 2017 as the WG began considering how unlicensed spectrum would be used in the upcoming 5G standard.

Another very important issue concerning the significance and value of most contributions to the SSO is the sheer volume of all them and the fact that the vast majority are not even reviewed in the WG meetings, let alone approved. This would be an impossible task. For example, there were a total of 1,225 contributions to RAN1 80b in April 2015, including consideration of all other technologies for prospective standardization. That is a rate of one every 90 seconds. That was a typical meeting that lasted four days and had 239 in attendance. The number of contributions per meeting doubled since then and toward the end of 2016 as activity levels rose with 5G standard setting for upcoming 5G.

Meanwhile, Qualcomm was among the very first companies to reveal the results of its technological developments, largely from in-house R&D, in a demonstration of LTE in unlicensed technology at the Mobile World Congress in Barcelona, February 2015.[37] This was less than a year since any Study Items on this topic were first proposed and two months after the Work Item identified for LAA was approved. This trade show demonstration was two-to-three months before the number of companies and contributions on this topic to the RAN1 WG peaked in April and May, respectively, that year.

LTE in unlicensed demonstrated superior speeds, capacity and co-existence versus Wi-Fi. Qualcomm conducted several live tests including of co-existence between LTE-U and Wi-Fi. Qualcomm collaborated with operators such as KT and infrastructure vendors including Alcatel-Lucent, Huawei, Nokia Networks, Samsung and test equipment manufacturer Rhode & Schwarz at the trade show.

Deutsche Telekom and Qualcomm conducted the world's first over-the-air LAA trial in Nuremburg, November 2015.[38] This was before the specifications for LAA were frozen in Release 13, March 2016.

9.4 Synopsis of significant milestones and outlook

There were many developments leading up to the development, standardization and implementation of LTE in unlicensed spectrum including foundational pre-requisites such as dual-carrier and dual-band carrier aggregation. These are rooted in inventions and innovations which date back to around the turn of the millennium.

Those technologies that use alternatives to conventional licensed spectrum began to be showcased in public presentations and demonstrations from around early 2013.

However, it was not until the end of 2013 before 3GPP began to consider these in its TSG plenary meetings and it was not until October 2014 before there were any technical contributions to the standard-setting process at the WG level. By then, a large proportion of the foundational work with the key inventions and with development work on these had already been completed, as summarized in Exhibit 12.

[37] https://www.qualcomm.com/news/releases/2015/02/26/qualcomm-extends-lte-unlicensed-spectrum-enhance-mobile-experiences-and and https://www.qualcomm.com/documents/expanding-lte-unlicensed-spectrum-infographic

[38] https://www.telekom.com/en/media/media-information/archive/world-s-first-lte-licensed-assisted-access-over-the-air-trial-363154

Exhibit 12: Some significant milestones toward LTE in unlicensed spectrum

2006	Standardization of multi-carrier capabilities by 3GPP2 in CDMA2000 EV-DO Rev B
2009/03	Standardization of Carrier Aggregation by 3GPP in WCDMA with Dual Cell HSDPA (3GPP Release 8)
2009/03	Standardization of LTE by 3GPP (also in Release 8)
2010/03	Standardization of Dual Band HSDPA enabling Supplementary Downlink (Release 9)
2011/06	Standardization of Carrier Aggregation in LTE Advanced (Release 10)
2011/12	AT&T acquires unpaired spectrum for supplemental downlink with HSPA+.[39]
2013/02	Nokia Siemens Networks and Qualcomm demonstrate Authorized Shared Access at Mobile World Congress in Barcelona.[40]
2013/12	Ericsson and Qualcomm propose LTE in unlicensed to 3GPP at TSG RAN #62 meeting
2014/01	CMCC, Ericsson, Huawei, Qualcomm and Verizon host impromptu non-3GPP workshop on LTE in unlicensed spectrum.[41]
2014/03	CMCC, Verizon & others propose LAA Study Item at TSG RAN #63[42]
2014/06	33 companies contributing 17 TDocs with "unlicensed" in title (6 included "LTE-U" and 2 included "LAA") at RAN WS14 workshop
2014/10	50 companies contributing 98 TDocs with LAA in the title at RAN1 78b which was the first RAN1 meeting to consider use of LTE in unlicensed spectrum
2014/12	Ericsson, Qualcomm, Huawei and Alcatel-Lucent submit Work Item description at TSG RAN #66 meeting
2015/02	Qualcomm runs live tests of co-existence between LTE-U and WiFi at Mobile World Congress trade show in Barcelona.[43]
2015/06	Ericsson, Huawei, Qualcomm and Alcatel-Lucent proposed a new Work Item at TSG RAN#68.[44]
2015/11	T-Mobile in Germany is the world's first operator to trial LAA trial over-the-air.[45]
2016/03	Technical specifications for LAA standardization were frozen as part of LTE Advanced Pro in Release 13
2017/06	T-Mobile USA is the first national operator to offer LTE-U to its customers.[46]
2017/11	AT&T was the first carrier to launch LAA commercially as part of its Gigabit LTE capabilities.[47]

LTE in unlicensed was being demonstrated publicly to show its superior speeds, bandwidth and co-existence versus Wi-Fi at the Mobile World Congress in February 2015, two-to-three months before the number of companies and contributions to the RAN1 WG on this topic peaked a in April and May

[39] https://www.fiercewireless.com/wireless/fcc-approves-at-t-s-1-93b-purchase-qualcomm-s-700-mhz-spectrum

[40] http://wireless.fcc.gov/workshop/PANEL%201-2%20Prakash%20Moorut%20-%20Nokia%20Siemens.pdf

[41] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_63/docs/RP-140060.zip

[42] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_63/docs/RP-140481.zip

[43] https://www.qualcomm.com/news/releases/2015/02/26/qualcomm-extends-lte-unlicensed-spectrum-enhance-mobile-experiences-and

[44] http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_68/Info_for_workplan/new_approved_WI_47/RAN1_3/RP-151045.zip

[45] https://www.telekom.com/en/media/media-information/archive/world-s-first-lte-licensed-assisted-access-over-the-air-trial-363154

[46] https://newsroom.t-mobile.com/news-and-blogs/lte-u.htm

[47] https://www.rcrwireless.com/20171117/carriers/att-laa-gigabit-lte-plans-tag17

that year. And, standard setting activity there continued at more than two-thirds that level for another year before subsiding substantially, followed by an uptick in 2017 as the WG started to consider how unlicensed spectrum would be used in the upcoming 5G standard.

It is still very early days in commercial use of LTE in unlicensed spectrum. Whereas LTE-U was specified more quickly and therefore has been trialed and commercially implemented more rapidly than LAA, it is the latter that is drawing most interest and commitment from mobile operators. LAA is being deployed in many networks worldwide.[48] LAA-ready devices such as Samsung's Galaxy S8 and later models are significantly seeding the market so that there is a user base for LAA-based services as these are activated commercially and rolled out. [49]

LAA has enormous potential and substantial uptake is anticipated over the next few years.[50] The cellular industry has always been significantly constrained by the limited availability and high cost of spectrum. As currently standardized, in the 5GHz unlicensed band, this will unleash more than 100MHz bandwidth for use by not only one but all operators. That will increase competition in mobile which will significantly stimulate supply and demand.

10 Analysis and conclusions

Most developments in standard-essential technologies for cellular communications largely arise from the inventions and innovations of a small number of luminaries and technology-developing firms. They also pioneer and promote the technologies they have developed by building support and consensus for these among many other companies who, as a result, make contributions to the standard setting process in their own right or add their names to the contributions of others.

New inventions, including some of those that are patentable by their inventors, trigger an avalanche of activity within companies and among others in development of technologies, with greatly expanded participation in the process of evaluating technologies and selecting from among those for inclusion in standards. Measuring activity in only the last and most visible part of this process does not accurately reflect where, let alone the value of, what is developed earlier or outside the SSO. That is rather hidden from view like the large submerged part of an iceberg: standards setting is like the smaller, visible, part of an iceberg above the waterline.

Joint contributions indicate coalitions of companies proposing specific technologies for inclusion in a standard. Joint contributions do not necessarily mean there are joint technology developments among some or any of the contributors. Technologies developed in collaborations among different companies are most likely to be complementary and, if patentable, are generally patented separately.

Cellular technology development and standard setting is a repeat game. Since the industry's inception 35 years ago, it has already gone through four major development cycles with generational upgrades and has implemented numerous technical improvements. Many technologies have been recycled, further improved and extended in subsequent technology generations. Much of this follow-on innovation is also substantially from the same companies that developed those

[48] *LTE in Unlicensed Spectrum, Global Mobile Suppliers Organisation, October 2017* http://www.communicationstoday.co.in/images/reports/20171011-LTE-in-Unlicensed-Spectrum-Oct-2017.pdf
[49] https://www.rcrwireless.com/20180114/analyst-angle/analyst-angle-how-to-provide-gigabit-lte-cheaply-when-you-dont-have-the-spectrum-Tag9
[50] Id.

technological foundations. LTE-LAA is a great example of this because it builds on already-standardized technologies to aggregate multiple carriers and different frequency bands.

In the case of taking LTE into unlicensed spectrum, most of the companies supporting initial workshop contributions were from mobile network operators, with interests primarily as customers for the prospective new technology rather than as technology developers or manufacturers. Mobile network operators hold a lot of sway in determining which technologies are selected for standardization in cellular, but rarely do much of the standard-essential technology development work. They tend, by any reckoning, to hold only small proportions of standard-essential patents.

Innovation is more about quality than quantity. TDoc contributions to 3GPP Working Groups cannot provide an accurate measure innovative value to the 3GPP standards. It is not even possible for most of them to be discussed in meetings, and only a small minority of them are ever approved.

This and the fact that many contributions include several or many company names shows that consensus for technology selection is largely being built outside of 3GPP meetings. This significant time and effort is not reflected directly or proportionately in the numbers of contributions. In many cases, the originator of an innovation for approval in a standard is not at all apparent in any 3GPP records. Data gathering can also lead to significant inaccuracies. There are often significant differences between the numbers of companies listed on the TDocs themselves and the summaries of these on 3GPP's online document listings.

Notwithstanding the high volume of activity in 3GPP, as indicated by its meeting submissions and attendance figures, this pales in comparison to outside R&D efforts. The latter significantly aligns with company revenues among those like Ericsson, Huawei, Nokia and Qualcomm that spend between 15% and 25% of their multi-billion-dollar sales on R&D last year.

More than 200,000 patents in tens of thousands of patent families have been declared possibly essential to 3GPP's standards by more than 200 of companies. While it is not possible to determine companies' shares of innovative value in these standards accurately by counting contributions or SEPs,[51] the overall value is clearly substantial in this large industry sector that keeps demonstrating such rapid technological advance.[52]

SSO activity metrics such as contribution counts can only ever be a weak indicator of where innovation is occurring and where value is generated in the standards. SSO activity skews to the later stages of innovation and does not reflect the significant work innovators do outside SSO activities.

In a cellular marketplace worth trillions of dollars, with value and growth significantly driven by recent technologies such as LTE Advanced, LAA and upcoming 5G, is it important to identify where and how much value is generated and exchanged in SEP technologies. Innovators' rewards should be commensurate with that—as exemplified in numerous executed licenses—not based on simplistic counts of contributions to SSOs or patents.

[51] http://www.ip.finance/2017/05/do-not-count-on-accuracy-in-third-party.html

[52] Keith Mallinson, Don't Fix What Isn't Broken: The Extraordinary Record of Innovation and Success in the Cellular Industry Under Existing Licensing Practices, 23 Geo. Mason L. Rev. 967 (2016)

Appendix

LTE-LAA: Technology developments, regulatory and commercial factors

A.1 Cumulative effects in technology development

Examples of major cumulative advances in cellular air-interface technologies that have enabled 100,000-fold increases in maximum data rates, from only about 10 kbps until around 2000 to 1 Gbps today, among numerous other improvements, include:

1. Analog to digital
2. TDMA to CDMA-based waveforms
3. Circuit to packet-based architectures
4. Wider-bandwidth carriers with OFDMA
5. Carrier aggregation, including different bands and the combination of licensed with unlicensed spectrum

Digital significantly increased spectrum efficiency over analog. Code-based radio technologies also enabled significantly greater frequency reuse with innovations including fast power control and soft handover. High-speed packet network capabilities, first in CDMA2000 EV-DO, then HSDPA and eventually LTE, exploited full power and rate control with innovative channel coding and scheduling to maximize data rates. High-speed packet data also brought significant change with flattening of the core network, which also enabled lower latencies.

Muliti-carrier technology in CDMA and the equivalent carrier aggregation in HSPDA overcame constraints on maximum carrier bandwidth in these code-based systems, of 1.25MHz and 5MHz respectively, to multiply peak data rates in proportion with total bandwidth while also providing statistical multiplexing gains on average throughput. While basing LTE on an OFDMA waveform enabled much wider bandwidths of up to 20MHz contiguously, multi-band CA was also introduced in LTE and is being widely adopted by operators because, in practice, most of them tend to have rather fragmented spectrum holdings with significantly less than 20MHz contiguously in most bands. Aggregating additional carriers in separate unlicensed spectrum was the next step with standardization of LTE-LAA.

LTE-LAA is but one example, showing how an innovative new technology is massively dependent upon and builds upon some major technological building blocks that were developed, implemented and refined over a decade or two. There are many more examples of cellular technology advances in standards including those to introduce or improve audio quality, network coverage, positioning, network security, data broadcasting, device-to-device communications and self-optimizing networks.

A.2 Why put LTE in unlicensed spectrum?

Why bother with LTE in unlicensed bands when Wi-Fi is already widely used by mobile operators to “offload” traffic from LTE in licensed spectrum? Some mobile operators have expressed frustration over Wi-Fi offload, which was necessary to avoid overload on their cellular networks and provide their subscribers a better-quality experience, but it allowed them less control over end-to-end traffic.

Unsurprisingly, some operators with extensive Wi-Fi hotspot networks were at least initially resistant toward putting LTE in unlicensed spectrum with LTE-U. AT&T and BT with huge investments in Wi-Fi hotspots were initially opposed to LTE-U but have been more amenable to LAA, which includes additional interference mitigation with Listen-Before-Talk (LBT). Major operators that have not bet

so much on Wi-Fi but were receptive to LTE-U include Verizon, China Mobile, NTT DoCoMo, Deutsche Telekom and TeliaSonera. A key benefit with LTE-U was faster time-to-market than LAA, but the former is not a 3GPP standard and the latter is. Most operators now favor LAA, including those who started with LTE-U, such as T-Mobile in the US.[53]

In summary, key benefits of LTE in unlicensed spectrum are:

- Enhanced user experience with licensed anchor for control and mobility
- Better capacity and range compared to Wi-Fi
- A good neighbor to Wi-Fi, going beyond minimum requirements to ensure fair coexistence
- Unified LTE network with common management of licensed and unlicensed spectrum

Making LTE work in unlicensed spectrum and doing so with minimal disruption to incumbent Wi-Fi users required the development of various techniques and extensive testing to show that LTE in unlicensed frequencies would be at least as good a neighbor as another Wi-Fi access point. Fair spectrum usage between LTE and Wi-Fi links needs to be maintained for coexistence in various usage scenarios. While this was demonstrated for LTE-U, operators everywhere are increasingly moving to LAA.

It was a regulatory requirement to use LAA, that includes the LBT using Clear Channel Assessment Procedures and channel occupancy limits, in regions such as Europe and Japan. Whereas LTE-U was based on 3GPP specifications, full standardization for this was completed outside 3GPP by the LTE-U Forum.[54] LAA was entirely standardized at 3GPP. Operators tend to prefer the latter, all other things being equal. The significant advantage of LTE-U was in the timing of its availability. LAA has effectively caught up now.

A.3 CA was an essential foundation for LTE-U and LAA

It might seem that putting LTE into unlicensed spectrum only entailed recently-developed technology because LTE in unlicensed spectrum was not even proposed as a Study Item until the TSG RAN #63 plenary in March 2014. It was first standardized at 3GPP, in the form of LAA, in Release 13 (March 2016). However, the key foundations for this innovation started to be laid a couple of decades earlier.

LTE in unlicensed is a form of carrier aggregation, the latter being a technology that has been developed and introduced in various standards over many years. Carrier aggregation (also referred to as multi-carrier) was first touted in the early 2000s as a means of providing higher speeds to CDMA2000, that used relatively narrow 1.25Mhz carriers, versus wideband CDMA (WCDMA) with 5MHz carriers. Multi-carrier CDMA was ultimately standardized by 3GPP2 in CDMA EV-DO Rev B in 2006 with compliant products available the following year.[55]

The means to aggregate adjacent carriers was also added to 3GPP's WCDMA with what is called Dual Cell High Speed Downlink Packet Access (DC-HSDPA), as was standardized In Release 8 (2009). In Release 9, Dual-Band (DB) DC-HSDPA operation was standardized, which enables the Supplementary Downlink (SDL) feature in a non-adjacent carrier using unpaired spectrum.[56] Release 10 extended

[53] https://newsroom.t-mobile.com/news-and-blogs/lte-u.htm
[54] http://www.lteuforum.org/
[55] https://news.thomasnet.com/companystory/qualcomm-unveils-2007-roadmap-for-ev-do-rev-b-514192
[56] There are two main deployment options for aggregating unlicensed spectrum: Supplemental Downlink (SDL) and TDD. In the SDL mode, unlicensed spectrum will only be used for the downlink, so that the data rates and capacity are greatly increased only in the downlink. This is beneficial to address the typically heavy traffic in

DB-DC-HSDPA to a total of four carriers across the two bands, which enables the aggregation of up to three SDL carriers with a serving carrier in the paired spectrum band.

High demand for data capacity had prompted operators to look for additional spectrum, including unpaired spectrum, to augment Frequency Division Duplex (FDD) deployments in the downlink, where there is the greatest need due to inherent asymmetry of data traffic between downlink and uplink. SDL provides a simple way to add unpaired spectrum (i.e., in a different band) to the downlink of existing Single Carrier deployments. The SDL carriers are configured in the unpaired band. Up to three carriers from the unpaired spectrum can be bonded with one carrier in the paired spectrum for devices that are Release 10 capable compliant.[57]

The ability to aggregate non-adjacent carriers, including those in different bands was an essential perquisite for LAA, which relies on an anchor carrier in licensed spectrum and bonds it to an additional carrier in a separate, unlicensed band.

LTE did not include CA when it was initially standardized in Release 8; it was added in Release 10 (2011), which was the first release for LTE-Advanced.

A.4 Where LTE was taken into unlicensed spectrum

Operators have increasingly used unlicensed spectrum to opportunistically offload the "best-effort" class of data from their 3G/4G networks. Many operators have their own Wi-Fi networks, sometimes referred to as "Carrier Wi-Fi."

By 2010, the cellular industry was striving to establish more seamless interworking between use of licensed and unlicensed spectrum, especially with LTE. Bringing LTE Advanced into unlicensed spectrum takes this effort to the extreme, by using the same technology and network for all spectrum types. This not only achieves the tightest possible technical integration, it also offers the most seamless user experience.

In this approach, the same small cells that offer LTE Advanced on licensed spectrum, also offer it on the 5 GHz unlicensed spectrum. Both bands are aggregated in the same way that different licensed bands are in LTE Advanced CA. There are significant benefits in having the same system use both spectrum types. From a mobile operator's perspective, a unified network for both licensed and unlicensed spectrum can use the same:

- core network
- small cells
- spectrum bands
- authentication systems
- operations and management systems
- acquisition, access, registration, paging and mobility procedures

The primary use case for bringing LTE Advanced to unlicensed spectrum is for LTE operators to augment their network capacity and provide higher peak data rates. The targeted bandwidth-rich 5 GHz band has potentially up to 500 MHz of available spectrum.

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the downlink. In the TDD mode, the unlicensed spectrum will have both downlink and uplink, just like a typical LTE TDD system, and it works like a typical LTE TDD carrier aggregation.

[57] Carrier aggregation in HSDPA including SDL is described in detail in a June 2014 White paper by Qualcomm: https://www.qualcomm.com/media/documents/files/benefits-of-hspa-supplemental-downlink.pdf

For operators, a unified network with LTE-U or LAA provides significant advantages compared to the current Carrier Wi-Fi option. As can be expected from a coordinated and managed architecture, LTE in the unlicensed spectrum offers higher performance than Wi-Fi for the same transmit power. This improvement is derived from multiple aspects of LTE. For example, LTE has a better and more robust air link structure designed specifically for mobility. LTE's coordinated and synchronized architecture makes the best use of resources by managing and mitigating the interference. The mandatory anchor in the licensed spectrum ensures that control signaling is always efficiently delivered and, above all, seamless mobility is achieved. A common set of signaling for both licensed and unlicensed spectrum reduces the overall overhead. Studies indicate a two-fold or more increase in performance as compared to Wi-Fi.[58]

Developing the above required various innovative technologies including those to ensure LTE was not causing unacceptable interference to other unlicensed users, including those on Wi-Fi or also using LTE, including those on other operators' networks, in the same frequency band. Cellular technology innovators have developed many features to avoid and mitigate interference, as well as to share the resources proportionately and fairly, when using the same channel, to be a "good-neighbor" to Wi-Fi.

That was made possible through technology development and proven through extensive testing.[59]

A.5 Different development paths and outcomes for LTE in unlicensed spectrum

With useful foundations in CA and in LTE, conditions were suitable to use unlicensed spectrum as well as licensed spectrum for LTE. LTE-U is a kind of precursor to LAA that does not include the LBT functionality for interference avoidance that is in LAA.

However, many members preferred 3GPP to focus on LAA for a variety of reasons including regulatory requirements. On that basis, the LTE Forum defined coexistence specifications for LTE-U based on 3GPP Release 12 (2015/03), for early time-to-market in certain nations (e.g., USA, Korea, India) where regulation does not require LBT.[60]

LAA was first included in LTE as part of LTE Advanced Pro in Release 13 (2016/03). 3GPP standards are also being used as the foundation for two variants of LTE in unlicensed spectrum which are being standardized outside 3GPP. LAA is also being continuously improved in Working Group activities most recently for its inclusion in 5G.

Whereas it is technically possible to implement LTE in unlicensed spectrum without any use of licensed spectrum, this technological variant is only being standardized outside 3GPP by the MulteFire Alliance.[61] This is an international association formed in 2015, that is developing the global technical specifications and product certification for a technology based on 3GPP standards that employs LTE in unlicensed spectrum without the need for an anchor in licensed spectrum, where all the signaling occurs in LAA.

[58] https://www.qualcomm.com/media/documents/files/white-paper-extending-lte-advanced-to-unlicensed-spectrum.pdf

[59] https://www.qualcomm.com/media/documents/files/lte-unlicensed-coexistence-whitepaper.pdf

[60] http://www.lteuforum.org/

[61] https://www.multefire.org/

Some licensed mobile operators are fearful the technology will facilitate new market entry by companies without licensed spectrum. Mobile operators have significant sway in decision making at 3GPP.

Consequently, a lot of the innovative and other activities to develop these two non-3GPP variants are not apparent in 3GPP records and activity metrics. However, it is inevitable, that at least some of the results and benefits of this technical and organizational work will eventually, if not already, also be utilized within 3GPP standards including LAA.

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