

Patenting activity by companies developing 5G

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Patenting activity among 5G technology developers

Project team

This report was prepared by the Office of Policy and International Affairs and its Office of the Chief Economist at the United States Patent and Trademark Office (USPTO).

Mary Critharis

Christian Hannon

Andrew A. Toole

Richard Miller

Elaine Wu

Michael Diehl

Executive summary

The United States advocates for a vibrant digital economy worldwide that enables more citizens to benefit from the promise of 5G wireless communications networks. As the Biden administration and the private sector work to secure and accelerate the rollout of 5G and subsequent generation networks, interest has never been higher in 5G competitiveness. In that context, this report examines an important factor related to 5G competitiveness: patenting activity.

In recent years, many studies have attempted to identify a single global leader in 5G technologies. Because it is difficult to directly determine which company owns the most patent-protected technologies used in 5G networks, existing studies have examined company activity in 5G standardization work and patents and patent applications¹ declared potentially essential to 5G standards.

This report provides a broader perspective by examining more than one data set and by recognizing the variances in significance that patents have to a sophisticated technical standard, such as 5G.

Specifically, the report examines which companies have filed for more patents at the USPTO in four technologies that have seen the most patenting activity among declared patent filings: Management of Local Wireless Resources, Multiple Use of Transmission Path, Radio Transmission Systems, and Information Error Detection or Error Correction in Transmission Systems.² This approach narrows the focus to patent filings on technologies central to 5G innovation. In addition to measuring patenting activity in these four technologies, the report also examines certain patent filing attributes associated with greater value. By analyzing the question of 5G

Key takeaways

- Unique among studies on 5G patenting activity, this report examines both (1) overall global 5G patenting trends, and (2) patent filings and value indicators in the four most-patented 5G-related technologies.
- Based on the report's analysis of patenting activity, the six most active 5G companies are Ericsson, Huawei, LG, Nokia, Qualcomm, and Samsung.
- The findings of the report call into question claims that any single firm or country is "winning" the 5G technology race.

patenting activity from a variety of perspectives, the USPTO has generated a rich set of results that are arguably more informative of 5G competitiveness than prior studies.

The USPTO's examination shows that six 5G companies consistently competed in patenting activity: Ericsson, Huawei, LG, Nokia, Qualcomm, and Samsung.³ According to the data generated for the report, no single firm dominates 5G innovation at present.

In summary, the results suggest that there remains ongoing competition among these six 5G companies in patenting activity notwithstanding media claims that a single firm may lead. Given the complexity of the results, caution is recommended when reviewing media claims of 5G dominance.

1 The data examined in sections III and IV of this report include both patents and pending patent applications. This report uses the term "patent filing(s)" to refer to both patents and patent applications.

2 Although these technologies are generally relevant to the development of Open Radio Access Networks (Open RAN), this study was not designed and does not purport to present a representative analysis of 5G patent activity in Open RAN technologies. Rather, the examination of the four selected technologies is one focus of a multipart examination of 5G patenting. For more information on Open RAN, see Federal Communications Commission, Notice of Inquiry in the matter of Promoting the Deployment of 5G Open Radio Access Networks, GN Docket No. 21-63, March 18, 2021, available at www.fcc.gov/document/fcc-seeks-comment-open-radio-access-networks-0.

3 The corporate names for these firms are Telefonaktiebolaget LM Ericsson; Huawei Technologies Co., Ltd.; LG Corporation; Nokia Corporation; Qualcomm Incorporated; and the Samsung Group.

I. Introduction

The National Strategy to Secure 5G Implementation Plan calls on the U.S. government to “[attain] an informed understanding of the global competitiveness and economic vulnerabilities of United States 5G manufacturers and suppliers.”⁴ Prior studies make divergent claims on 5G leadership, likely as a function of the particular data examined and methodology applied. Given differing outcomes in prior studies, this report examines multiple data sets using different methodologies, with a focus on the types of patent families and patent attributes that economists associate with greater significance or economic value. By examining 5G patenting in different ways, this report generates a rich set of results that are useful in assessing 5G innovation.

Section II of this report reviews certain 5G standards development basics, including the requirement that technology contributors identify or “declare” any patents or applications that might be relevant to 5G standards. Section III presents results and analysis on which companies have declared more 5G-related patent families, including the so-called triadic⁵ patent families that economists generally regard as more useful information when comparing 5G-related patenting activity among global competitors. Section IV examines data not considered in any prior study, i.e., patent filings at the USPTO in the 5G-related technologies with the most intense patenting activity. This analysis permits the identification of the 5G companies that appear most active in these core technologies in the U.S. market. Also using the new data set, section IV examines five patent characteristics that economists generally associate with higher value. Conclusions are set out in section V.

II. Developing 5G standards

Technical standards provide the blueprints that guide equipment makers. Adhering to a common standard generally allows the equipment of different manufacturers to interface seamlessly. Standards can promote competition and benefit consumers.⁶

Development of 5G standards is proceeding under the umbrella of the 3rd Generation Partnership Project (3GPP). 3GPP is a standards development organization (SDO) comprising seven national telecommunications SDOs, termed “organizational partners.”⁷ 3GPP develops technical specifications for 5G networks that may then be adopted and published as standards by its organizational partners.

Most 5G standards development occurs in technical specification groups and working groups of the 3GPP. Participants submit technical contributions for consideration as the groups work to develop a specification that addresses a particular technological challenge. In the case of 5G, many of the submitted technologies appear in granted patents or pending patent applications. To help promote subsequent licensing transactions and avoid antitrust concerns, rules were established as part of the standards development process. One of these rules requires participants to identify patents and patent applications potentially essential to the final 5G standard. In particular, the European Telecommunications Standards Institute (ETSI), one of the organizational partners of the 3GPP, requires members submitting technical proposals to “draw the attention of ETSI to any of that MEMBER’S IPR [intellectual property rights] which might be ESSENTIAL if that proposal is adopted.”⁸

4 National Strategy to Secure 5G Implementation Plan, January 6, 2021, 11, www.ntia.gov/files/ntia/publications/2021-1-12_115445_national_strategy_to_secure_5g_implementation_plan_and_annexes_a_f_final.pdf.

5 As further discussed in section III, the economic literature sometimes defines a patent family as “triadic” if it has at least one patent application filed with, or patent granted by, each of the USPTO, the European Patent Office, and the Japan Patent Office.

6 See www.nist.gov/services-resources/standards-and-measurements.

7 The seven organizational partners of 3GPP are the Association of Radio Industries and Businesses; the Alliance for Telecommunications Industry Solutions; the China Communications Standards Association; the European Telecommunications Standards Institute; the Telecommunications Standards Development Society, India; the Telecommunications Technology Association; and the Telecommunication Technology Committee. See www.3gpp.org/about-3gpp.

8 ETSI, IPR Policy at Annex 6, Clause 4.1 (emphasis in original), April 14, 2021, www.etsi.org/intellectual-property-rights.

Despite great interest in identifying the company with the strongest 5G patent portfolio, the inquiry is hard to assess. Although contributors must declare patents that might be essential to the standard, it may be very difficult to ascertain which patents “read on” or claim the technologies incorporated in the final standard. Essentiality may be the subject of a good faith dispute, even when the parties devote considerable resources to analysis during licensing negotiations and litigation.

Absent reliable and comprehensive direct information, existing studies have attempted to estimate 5G leadership by counting the number of technical contributions submitted by companies during standards development and/or the number of patents and applications that companies declare potentially relevant to the standard. Using these and other methodologies, four relatively recent studies⁹ reach different conclusions as to which company leads in 5G innovation. All of them, however, identify Ericsson, Huawei, Nokia, and Qualcomm, and three of them add LG and Samsung.¹⁰ The results generated for this report indicate that, at present, the six firms listed are the most active in terms of patenting activity.

III. Global and triadic patent families declared essential to 5G standards

This section examines families of patents and patent applications declared, as of May 2021, by companies as potentially relevant to 5G standards pursuant to the ETSI requirement (hereinafter ETSI-declared 5G patents).¹¹ In what follows, “global” (or “worldwide”) and “triadic” patent families are examined to help identify those companies most active in 5G patenting.¹²

Terms and methodology

Patent families are composed of patents and patent applications that claim the benefit to one “priority” application. A priority application is a patent application that is first filed in one jurisdiction and serves as the basis for patent filings in other jurisdictions. Patent treaties allow applicants to claim the benefit of the filing date in the first-filed jurisdiction when filing in other jurisdictions. Patent applications on the same subject matter filed in multiple jurisdictions are called patent families because they are all related to the first-filed application. Analyzing patent families may provide a better understanding of an entity’s inventive contributions because counting patents individually can overestimate a company’s inventive contributions.

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- 9 While the USPTO does not necessarily endorse these studies over others, each has received press attention and applied a range of methodologies. The four are as follows: Ericsson, “Estimating the Future 5G Patent Landscape,” October 26, 2018, www.ericsson.com/en/patents/articles/estimating-the-future-5g-patent-landscape; Guang Yang, “Who Are the Leading Players in 5G Standardization? An Assessment for 3GPP 5G Activities,” Strategy Analytics, March 16, 2020, www.strategyanalytics.com/access-services/service-providers/networks-and-service-platforms/reports/report-detail/who-are-the-leading-players-in-5g-standardization-an-assessment-for-3gpp-5g-activities?slid=1102435&spg=6; Tim Pohlmann and Knut Blind, “Fact Finding Study on Patents Declared to the 5G Standard,” IPlytics, January 2020, www.iplytics.com/wp-content/uploads/2020/02/5G-patent-study_TU-Berlin_IPlytics-2020.pdf; and Matt Luby, Muzammil Hassan, and Aman Kumar, “Exploration of 5G Standards and Preliminary Findings on Essentiality,” June 2020, <http://info.greyb.com/hubfs/5G%20Report%20-%201st%20Release.pdf>.
- 10 All but the Strategy Analytics study include Samsung and LG among the top 5G companies. Other companies listed include ZTE (in the IPlytics study) and China Mobile (in the Strategy Analytics study).
- 11 The initial data set included 141,564 patents and non-lapsed patent applications from the IPlytics database that had been declared essential to ETSI technology standards related to 5G wireless communications and its applications as of May 2021. These ETSI-declared 5G patents represent 42,712 patent families. The data set was pared down for analysis by removing all such patents that had been declared essential to standards that map to previous generations of wireless technology, such as 4G and 3G. The final population was 106,013 ETSI-declared 5G patents. Note that the declared essential patents are linked to firms on the basis of the firm that declares the patent potentially essential, which is not necessarily the firm to which the patent was initially assigned at grant. It is possible that some patents were obtained by firms and then declared potentially essential by the new assignees.
- 12 The database used in this section was originally developed by scholars from Northwestern University in the United States, the Technical University of Berlin in Germany, and Mines ParisTech in France. The database is now owned and managed by IPlytics, a commercial firm based in Germany. As discussed in footnote 11, the data set excludes patents and applications also declared potentially essential to prior generations of wireless technologies, such as 4G. This approach focuses the inquiry on newer technologies.

As used in this report, the term “global (or “worldwide”) patent families” includes those patents filed anywhere in the world. Examining global patent families declared essential to 5G standards is useful because it is a comprehensive practice. Such examination may, however, be misleading as to the value of the families if, for example, the patent owner files disproportionately in its home jurisdiction to the exclusion of filings in major foreign markets.

To address this concern, the report also examines “triadic” patent families. International organizations, such as the Organization for Economic Cooperation and Development (OECD) and the World Bank, have treated triadic patent families as a measure of national economic performance. They define a patent family as “triadic” if it has at least one patent application filed with, or patent granted by, each of the USPTO, the European Patent Office, and the Japan Patent Office. The OECD has explained:

In terms of statistical analysis, triadic patent families improve the international comparability of patent-based indicators, as only patents applied for in the same set of countries are included in the family; home advantage and influence of geographical location are therefore eliminated. Second, patents included in the family are typically of higher value, as patentees only take on the additional costs and delays of extending protection to the countries if they deem it worthwhile. By introducing de facto a cut-off point regarding the value of patents included in this set, the upper tail of the distribution of patents by value is selected (in terms of worldwide applications), making patent family counts more informative than national or regional counts.¹³

This report adopts the same definition of triadic patent families.¹⁴ The data examined in this section, from the IPlytics database as of May 2021, include roughly 106,000 ETSI-declared 5G patent filings.¹⁵ Seven companies filed roughly 70% of these patents: Ericsson, Huawei, LG, Nokia, Qualcomm, Samsung, and ZTE. Because ZTE filed so few triadic families, that company appears only selectively in the rest of this report.

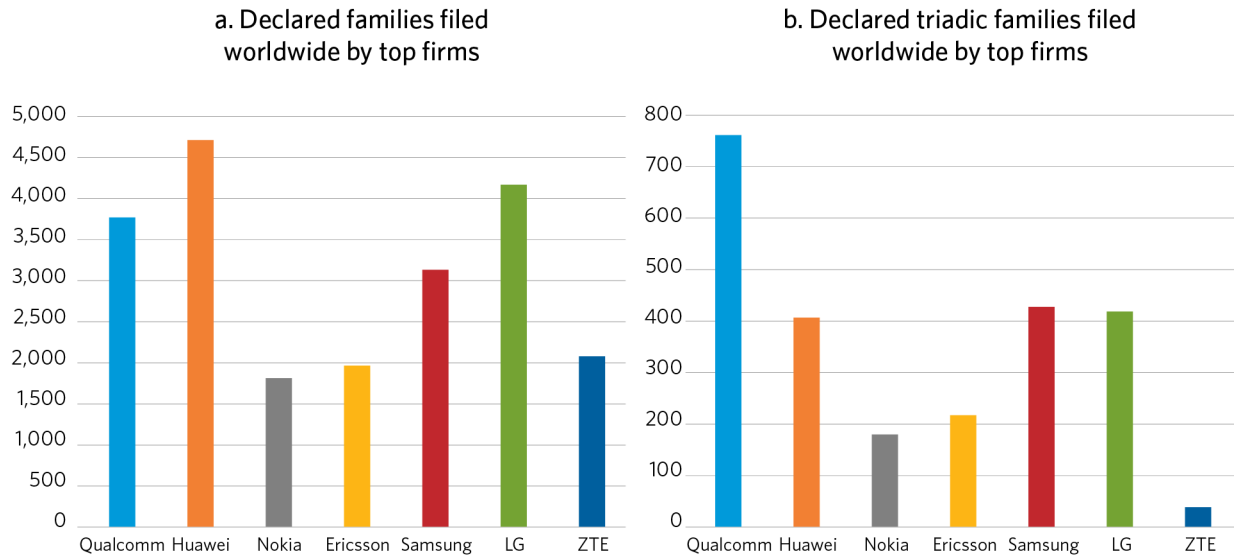
Results

Figure 1 contrasts worldwide and triadic family filings of ETSI-declared 5G patenting activity filed by the top seven firms.¹⁶ The data demonstrates that companies contrast sharply between worldwide and triadic families. According to the worldwide filings for the period examined, panel (a) of Figure 1 shows that Huawei filed the highest number of ETSI-declared 5G patent families worldwide, followed by LG, Qualcomm, and Samsung. Huawei’s declared filings were 12% more than those of the second-largest filer, LG, and nearly 25% more than Qualcomm’s. Of worldwide filings, ZTE has declared more patent families worldwide than Nokia or Ericsson.¹⁷

Using triadic patent families, as shown in panel (b), leads to different outcomes. First, using this higher threshold as a tool to examine patent value significantly reduces the number of patent families. The vertical axis in panel (b) reaches a maximum value of 800 triadic families compared to 5,000 patent families as shown in panel (a). An examination of triadic patent families during the same period as that for panel (a) suggests that Qualcomm is the most active filer of 5G patents,

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- 13 OECD, “Basic Criteria for Compiling Patent-Based Indicators,” in OECD Patent Statistics Manual, pp. 71–72 (Paris: OECD Publishing, 2009); see OECD, *Main Science and Technology Indicators*, no. 1 (Paris: OECD Publishing, 2020). Using the triadic family definition as a measure of value can be especially helpful when considering recent patent filings and grants because good information on other useful measures, such as forward citations or patent renewals, is limited in such instances. Triadic family members have been found to generate more forward citations than their counterparts. See George Messinis, “Triadic Citations, Country Biases and Patent Value: The Case of Pharmaceuticals,” *Scientometrics* 89, no. 3 (2011): 813–33. See also Hélène Dernis, Dominique Guellec, and Bruno van Pottelsberghe, “Using Patent Counts for Cross-Country Comparisons of Technology Output,” *Science Technology Industry Review* 27 (2001): 128–46.
- 14 With relatively few exceptions, the economic literature has, to date, generally defined “triadic” as consisting of these three markets. In the preparation of this report, USPTO economists additionally examined a data set limited to what might be termed “quadratic” patent families, including those with filings in the four markets that the most active declarers call home (the United States, EU, China, and South Korea). The results are not presented here because they differ little from those generated by the more widely embraced triadic approach. When using the quadratic approach, we still find that Qualcomm has the most families represented, followed by Samsung, LG, Huawei, Nokia, Ericsson, and ZTE.
- 15 See footnote 11.
- 16 Note that patent families can be identified only after patents or patent applications are made public. These “published” patents and applications are used in the analysis.
- 17 These findings are broadly consistent with results reported in the IPlytics study mentioned previously.

Figure 1: 5G-declared patent families



followed by Samsung, LG, and Huawei. It bears noting that this result is based on a “snapshot” of a particular point in time (May 2021), and that it is likely that some families that were not triadic may become triadic as new family members are published and/or declared essential.

Figure 1 also highlights how companies such as Huawei and Qualcomm differ in terms of worldwide and triadic 5G-related declarations. Of the roughly 4,600 patent families declared by Huawei, approximately 400 were triadic. In contrast, Qualcomm declared about a quarter fewer patent families than Huawei on a worldwide basis, yet it declared more than 750 triadic families. Samsung and LG rank high for both measures. ZTE displays the greatest contrast in worldwide and triadic filings. While ZTE joins other companies at the lower end of the range on a worldwide basis, it declared fewer than 50 triadic families, roughly one-sixth of the number declared by Nokia, which was the next lowest in the number of declared triadic families. Given that triadic families may be considered higher in value and that companies contrast sharply between worldwide and triadic families, both perspectives should be considered when evaluating patenting activity among 5G companies.

IV. Focus on the most patented 5G technologies and measures of competitiveness

This section reviews patenting activity at the USPTO in four 5G technologies, as well as patent filing characteristics associated with competitive patent portfolios. Limiting the examination to technologies with the most patenting activity among ETSI-declared patent filings at the USPTO permits additional comparisons among 5G companies in technologies that may be more central to their research efforts, at least in terms of the number of patents granted. The subsequent review of patent filing characteristics associated with competitive portfolios shifts the focus from the number of patent filings to information on their significance. Comparing the results of these inquiries to those reported in section III increases confidence in the overall conclusions of this report.

Patenting activity in the most patented 5G technologies

Four technologies with the most patenting activity at USPTO among ETSI-declared filings were identified by examining more than 22,000 ETSI-declared patent applications published by the USPTO during 2010–2021, a subset of the 106,000 ETSI-declared 5G patent filings.¹⁸ This inquiry is limited to filings at the USPTO because doing so permits comparisons among 5G companies that would not be possible across jurisdictions.¹⁹ Although 5G standards encompass a wide range of technologies, just four of them accounted for nearly half of the total ETSI-declared patent filings at the USPTO.²⁰ Within these four technologies, the six 5G companies mentioned earlier accounted for 75%–85% of patents and patent applications. Using the nomenclature of the Cooperative Patent Classification (CPC) system, the four selected technologies were:

- Management of Local Wireless Resources²¹
- Multiple Use of Transmission Path²²
- Radio Transmission Systems²³
- Information Error Detection or Error Correction in Transmission Systems²⁴

Table 1 (see page 10) presents the findings for the firms in the four technologies. For each company and technology, the table indicates the number of ETSI-declared 5G USPTO patents and applications and the number of unique global patent families. The table also provides the percentage of the 5G-declared patents and applications that are members of triadic families and the percentage of patent applications granted by May 2021.

With regard to patent activity in selected 5G technologies, no company emerges as the clear leader. Measured by the number of ETSI-declared 5G USPTO patent filings, LG is the most active filer in the categories of Management of Local Wireless Resources, Radio Transmission Systems, and Multiple Use of Transmission Path, while Qualcomm is most active in the category of Information Error Detection. If patent families are considered, outcomes for the four technologies are the same, except that Qualcomm is the most active filer in the category of Multiple Use of Transmission Path. Whether patents and applications or patent families are considered, Huawei is behind Qualcomm, LG, and Samsung in terms of filing activity. Samsung is typically the third-most active filer except for in the category of Radio Transmission Systems, where it ranks second.

Patent attributes associated with competitiveness

In a further analysis of the more than 22,000 ETSI-declared patent applications, this report examines various patent attributes associated with technological competitiveness. Although other factors are also relevant to determining innovative activity, economists have identified several characteristics of a company's patent portfolio as indicative of competitiveness, at least from a technology perspective. IPlytics computed a subset of these metrics for each relevant patent filing in its database, but the results for a company's portfolio broken out by the four selected CPC groups do not appear in the published literature. The five indicators included are as follows:²⁵

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- 18 A review of the IPlytics database found that 22,196 ETSI-declared patent applications had been filed at the USPTO since 2010. This count includes only granted patents and applications that were active as of May 2021.
- 19 When making comparisons on the indicators examined in this section, including patents from multiple jurisdictions is problematic, because the scores developed for the quality metrics are jurisdiction-specific. One can compare the scores within each jurisdiction, but not across jurisdictions. However, although patents filed at the USPTO have effect only in the United States, the U.S. market for 5G innovation is very large, making it an attractive place to seek a patent for 5G companies. Thus, as a complement to the global data presented previously, our focus in this section is patents filed in the United States.
- 20 This is not to say that technologies outside the four selected are not important. Other researchers may wish to examine patenting trends in additional 5G-relevant technology classes, for example, H04J 11 under the CPC.
- 21 This technology received the code H04W 72 under the CPC.
- 22 Code H04L 5 under the CPC.
- 23 Code H04B 7 under the CPC.
- 24 Code H04L 1 under the CPC.
- 25 Indicators were chosen based on relevance and IPlytics' ability to measure them given the data at hand.

- **Market coverage:** This metric reflects the collective gross domestic product of the countries spanned by the patent family in question. A patent filing in larger economies will have a higher score on this metric than filings in smaller economies. Market coverage is viewed as one indicator of patent value because applicants will have greater motivation to apply for patents in multiple jurisdictions if they think commercialization of the invention is possible and because exclusive patent rights are enjoyed over a larger economic area.²⁶
- **Technical relevance:** This metric reflects the number of times the patent or published application was cited as a prior art reference by another patent or application.²⁷ To mitigate any truncation issues that would skew results for newer patents and applications, the technical relevance measure is adjusted by controlling for publication year. However, given that many of these patent filings were published relatively recently, this measure should be viewed with caution.
- **Radicalness:**²⁸ This metric of economic novelty is calculated by counting the number of patents cited as prior art in a patent or application, taking into account the number of prior art citations made by cited patents. Generally, the lower the number of prior art citations, the higher the degree of radicalness. A high radicalness value indicates a high degree of novelty in a certain technological area.
- **Legal breadth:** This metric is calculated by counting the number of words used in the shortest independent claim. Generally, shorter independent claims indicate broader legal breadth and vice versa.²⁹ Broader claims are generally more valuable than narrower ones.
- **Scope:** The patent scope metric is the count of the number of distinct CPC subclasses that the examiner has used to classify the invention underlying the patent. A higher scope value reflects a wider technical applicability of the patented invention.³⁰

Figures 2 and 3 depict company scores on the five metrics for each of the selected 5G technologies. In this presentation, a higher score is plotted further away from the center.³¹

Reviewing Figures 2 and 3, several patterns emerge, but no single firm is dominant. On the “legal breadth” metric, Qualcomm is first, and Ericsson is second, followed closely by Nokia, while LG lags all others. Ericsson and Nokia generally score high on the “radicalness” measure, whereas Qualcomm and Samsung are at or near the top on the “technical relevance” scale. No strong differences emerge on the “scope” and “market coverage” metrics. Overall, the competitiveness metrics examined for the period in question suggest that the 5G-related patent portfolios of the six companies vary.

26 See OECD, “Measuring the Technological and Economic Value of Patents,” in *Enquiries Into Intellectual Property’s Economic Impact* (Paris: OECD Publishing, 2015), 92–93.

27 *Ibid.*, 103–6.

28 Kristina B. Dahlin and Dean M. Behrens explain that economic literature has contrasted incremental innovation on the one hand with radical or breakthrough innovation on the other. They assert that an invention is radical if it meets three criteria: (1) it is novel (dissimilar from prior inventions), (2) it is unique (dissimilar from current inventions), and (3) it is adopted (influences the content of future inventions). Dahlin and Behrens, “When Is an Invention Really Radical?: Defining and Measuring Technological Radicalness,” *Research Policy* 34, no. 5 (2005): 717, 722, www.sciencedirect.com/science/article/pii/S0048733305000764. For purposes of this report, the radicalness measure captures the backward-looking criteria just described. It is calculated by counting the number of patents a patent or application cited as prior art, taking into account the number of prior art citations made by cited patents. Generally, the lower the number of prior art citations, the higher the degree of radicalness.

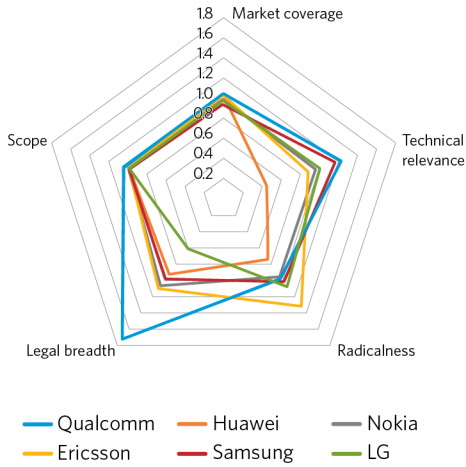
29 See Alan Marco, Joshua Sarnoff, and Charles deGrazia, “Patent Claims and Patent Scope,” *Research Policy* 48, no. 9 (2019).

30 See Joshua Lerner, “The Importance of Patent Scope: An Empirical Analysis,” *RAND Journal of Economics* 25, no. 2 (1994): 319–33.

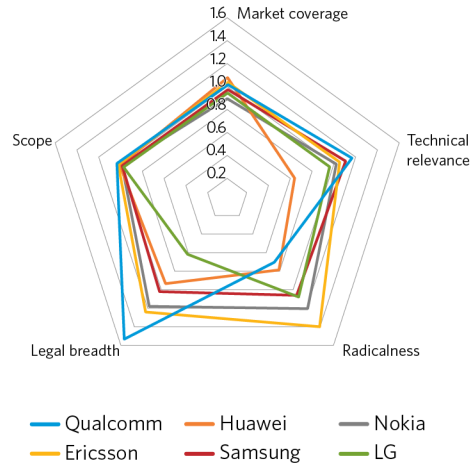
31 As part of the computation process, IPlytics normalized the averages of all patents/applications from the same patent office, cooperative patent classification subclass, and publication year. For ease of presentation in Figures 2 and 3, an additional normalization was applied to present the results of all the measures on the same scale. The normalization has no effect on the results, but it places all of the measures on the same scale for a better graphical presentation of the results.

**Figure 2: Comparing quality/value metrics in two CPC groups:
Management of Local Wireless Resources and Radio Transmission Systems**

Comparing quality/value metrics for top filers in management of local wireless resources

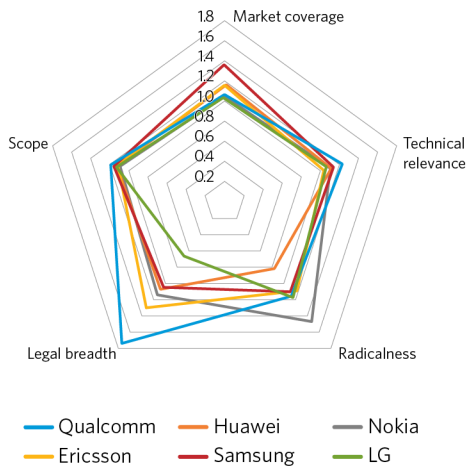


Comparing quality/value metrics for top filers in radio transmission systems

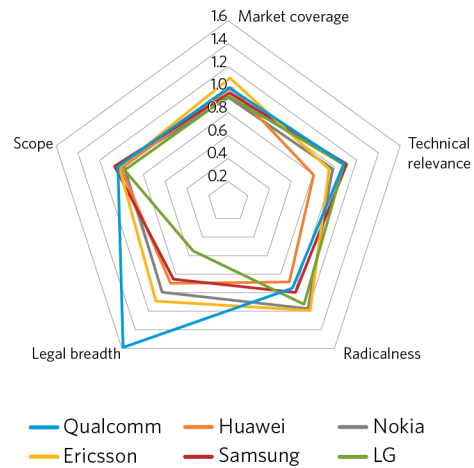


**Figure 3: Comparing quality/value metrics in two CPC groups:
Multiple Use of Transmission Path and Information Error Detection**

Comparing quality/value metrics for top filers in multiple use of transmission path



Comparing quality/value metrics for top filers in information error detection



V. Conclusions

By assessing the issue of 5G patenting activity from a host of new perspectives, this report casts a wider net and provides more information than previous patent studies in evaluating 5G competitiveness. According to data for the period examined, the USPTO's multi-part examination of 5G-related patenting activity suggests that no single firm is "winning" the 5G technology race. Although no company consistently led in the results generated for this report, the analysis supports three key findings.

First, the six firms reviewed in this study—Ericsson, Huawei, LG, Nokia, Qualcomm, and Samsung—consistently filed more 5G-related patent applications than other companies. ZTE is sometimes mentioned as a seventh competitor, but during the period examined in this report, its patents and applications were more highly concentrated in its home market, and its patenting activity in foreign markets was smaller relative to the other six firms.

Second, according to the results generated, no single firm appeared to dominate 5G-related patenting during the period examined. While Huawei filed the most 5G-related patent families, Qualcomm filed

the most in triadic patent families (i.e., those filed in the United States, the European Union, and Japan). In four technologies with the most patenting activity among ETSI-declared filings, which account for about half of all 5G patent applications filed at the USPTO, LG and Qualcomm emerged as the most active, depending on the technology and whether patents or patent families were considered. Samsung was most often third, and Huawei was fourth, both ahead of Ericsson and Nokia.

Third, an examination of indicators that may collectively speak to patent portfolio competitiveness did not reveal a consistent leader. For the period examined, Qualcomm's patent claims had the greatest legal breadth, whereas LG trailed all others on this measure. Ericsson and Nokia ranked higher in terms of radicalness (i.e., indicating fewer prior art citations against an application during prosecution), and Qualcomm and Samsung most often led on the metric of technical relevance.

Table 1: Portfolios of ETSI-declared 5G USPTO patent filings by the major filers in four selected technology areas, 2010-2021

	Qualcomm	Huawei	Nokia	Ericsson	Samsung	LG
Management of local wireless resources						
Declared patents and applications						
Number of patent filings	546	343	169	197	493	932
% Triadic	45	23	31	43	39	42
% Granted	69	88	89	92	87	93
Number of families	433	268	139	130	301	552
Multiple use of transmission path						
Declared patents and applications						
Number of patent filings	640	249	70	109	437	793
% Triadic	38	30	27	45	34	40
% Granted	70	88	91	86	86	91
Number of families	524	189	66	79	327	516
Radio transmission systems						
Declared patents and applications						
Number of patent filings	216	175	36	110	284	372
% Triadic	38	37	19	42	31	41
% Granted	75	97	92	92	92	93
Number of families	168	132	34	76	228	258
Information error detection or error correction in transmission systems						
Declared patents and applications						
Number of patent filings	304	122	40	100	226	258
% Triadic	37	30	23	45	32	42
% Granted	72	97	93	96	89	88
Number of families	266	101	39	69	181	184