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Technology Niche Analysis®

Radio Direction Finding System

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Science/Technology Fields: antennae, radio signals
Technology Type: Product
International Patent Classification: H01Q, G06F
Geographic Region: Global

SAMPLE

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Executive Summary

The function of Technology Niche Analysis® report is to provide data that can be used to help small businesses strategically position their technology in the specific market niche. Our findings are based on an examination of the material provided by the client, conducted interviews and Web searching.

The key findings are:

- **Innovation Being Commercialized:** Reconfigurable radio signal direction finder antenna for millimeter wave technology.
- **Intellectual Property:** Patents for estimating the direction of arrival of radio signals using a reconfigurable antenna.
- **Major Substitutable Products and Technology That Already Exists:** Lower frequency radio waves.
- **Commercialization Strategy Considerations: L**icensing the technology for use by multiple industries.
- **Examples of Potential Targets**: Cell phones**,** marine, aerial, defense, and tracking.
- **Value Proposition:** Provide small-scale antenna that estimates the radio signal angle-of-arrival which is then used to steer/reconfigure the antenna to find/maximize the signal.

Introduction

The following is a generic description of this technology.

Description of Technology
Reconfigurable antenna radio direction finder system

This technology is a reconfigurable radio direction finder antenna technology that estimates the angle-of-arrival (AOA) of radio signal using receiver and antenna system which estimates the low resolution of the AOA, then simulates the high-resolution estimate of AOA which is then used for the steering/reconfiguring the antenna.

The more specific non-proprietary description is:
A small, reconfigurable antenna with computer processing algorithms estimates the arrival angle of a radio signal including millimeter waves. The angle-of-arrival (AOA) estimate takes place in multiple stages:

- A wideband receiver system covering 360 degrees estimates the frequency of the incoming signal.
- Components sweep through different frequency family configurations that boost or attenuate the received signal to determine a coarse function of AOA mapping the strongest return in a low-resolution estimate of the arrival angle.

- Using this coarse estimate, further analysis obtains a high-resolution, more specific AOA estimate.

Simulated results indicate that this device estimates arrival angles just as accurately as larger multi-element systems that rely on more complicated steering mechanisms to find the target.

The invention estimates the direction of the arriving signal at the receiving antenna and uses that information to reconfigure the antenna to take advantage of the signal.

What makes this technology a scientific/engineering innovation is:
Other technologies use a multi-element antenna or rotatable directional antenna whereas this antenna reconfigures based on frequency resonances covering the azimuth of 360 degrees. Previously this reconfigurable radio direction finder system was used to estimate and refine the pointing of antennas of radio waves and is now expanded to include 5G and millimeter wave technology. This wideband omnidirectional small- scale antenna determines patterns based on different pointing directions with narrower beams for more accurate estimates of direction of arrival.

The client wishes to determine the feasibility of the reconfigurable antenna for the millimeter wave technology, and find interested, viable commercial partners, more specifically, a partner for research and development and a commercialization licensing arrangement.

An application is a potential use for a technology that is based on end-user needs and could provide a feasible market opportunity for a technology. The following table is an option for initial market entry.

Viable Application
Telecommunication: phones, smartphones, tablets, social networking, mobile video

“The Angle of Arrival (AOA) is a method for determining the direction of propagation of a radio-frequency wave incident on an antenna array. AOA determines the direction by measuring the Time Difference of Arrival (TDOA) at individual elements of the array -- from these delays the AOA can be calculated. A current application of AOA is in the geodesic location or geolocation of cell phones. The aim is either to comply with regulations that require cell systems to report the location of a cell phone placing an emergency (i.e., 911) call or to provide a special service to tell the bearer of the cell phone where he is. Multiple receivers on a base station would calculate the AOA of the cell phone's signal, and this information would be combined to determine the phone's location on the earth. Also, AOA is generally used to discover the location of pirate radio stations or of any military radio transmitter. In submarine acoustics, AOA is the method to localize objects with active or passive ranging. Wireless locating is used in

Global Positioning Systems (GPS), GLONASS, Indoor positioning system, Satellite navigation systems, Telematics and Tracking. ”[1]

According to an associate professor in Syracuse University’s College of Engineering and Computer Science, when moving to higher frequencies the transmission range gets shorter, unable to penetrate walls as easily and line-of-site else loss of attenuation in the signal. Smaller cell/portable base station microcells require smaller and more antennas packed into devices enabling directional transmissions to steer the signal.

The expansion into higher frequencies provides larger availability and higher transfer rates for near perfect video streaming and real-time gaming with reduced clutter and high immunity to jamming and interference. They are susceptible to restrictions due to foliage, atmospheric absorption and scatter (rain/fog), line of sight issues and brightness temperature as absorb high frequency electromagnetic radiation which then degrades the receiver antenna performance.[2]

We also identified other potential applications for the technology.

Other Applications Identified	
Application	***Basis for Feasibility***
Radar, satellite, military	Security, search and rescue
Internet of Things	Exponentially expanding range of types of devices connected digitally[3]
Industrial automation	Robotics
Networking/grid	Vehicular networks for electric cars, smart power grid rerouting electricity
Medical applications	Neuroengineering, cardiovascular engineering, electophysiology[4]

Methodology Used for this Study

The Technology Niche Analysis® (TNA®) report assesses the needs, preferences, barriers, and competition for the customer’s technology. It provides a roadmap for entering the specific market and identifies companies interested in helping to transition the technology. These

[1] Angle of arrival (AOA), Wikipedia, https://en.wikipedia.org/wiki/Angle_of_arrival (accessed January 15, 2017).
[2] “Millimeter waves: How we got here, the physical challenges, and 5G opportunities”, Nutaq of NuRan Wirless, http://www.nutaq.com/blog/millimeter-waves-how-we-got-here-physical-challenges-and-5g-opportunities (accessed January 6, 2017).
[3] Larry Greenemeier, “5G Wireless? Wireless companies want next-generation gadgets to download at rates of gigabits per second. The question is how to make it happen,” Scientific American, June 23, 2015, https://www.scientificamerican.com/article/will-millimeter-waves-maximize-5g-wireless/ (accessed January 6, 2017.)
[4] "The world's first academic research center combining Wireless, Computing, and Medical Applications". NYU Wireless. http://www.nyu.edu/about/news-publications/news/2012/august/nyu-and-nyu-poly-launch-worlds-first-academic-research-center-to-combine-medicine-with-wireless-communications-and-computing.html (accessed January 6, 2017).

companies are potential partners that will provide money, support, facilities, or other required resources.

Foresight begins solving the commercialization puzzle by using the customer's definition of the technology's performance specifications and characteristics. These are used as guides when conducting online data searches and interviews with experts. We also collect our customer's preferences for commercializing the technology and use them as a secondary guide.

Please note that in today's rapidly changing global markets, it is unlikely that a single, "best possible" entry strategy exists. Even with the informational resources of the Internet, this remains true, especially for a study such as this that is constrained by budget and time. Thus, the findings and recommendations presented here are *preliminary*. Additional market research may lead to modifications or substantial revisions. Although we strive to describe trends that will be important over a five-year window, market and technology developments are dynamic. Events can overtake the data and analysis presented.

Competitive Opening

End-users are likely to be interested in this technology because of the following advantages it can bring. We have contacted the following expert to gauge his/her views on the technology's potential competitive opening. These findings are presented in the table below.

Expert on Competitive Opening	
Name	EXPERT
Title	Communications Technology Architect
Organization	XX
Phone	XX
E-mail	XX
Interview notes and comments in regard to importance of the need being addressed, key specifications that may appeal to the end-users, market dynamics, competition, price factors, and market entry strategies.	This is a tough, very competitive market with competition from Cisco, Ruckus, Semtech and Trimble. Prior entries included Bluetooth LE, LoraWan, Ruckus, RFID and BT Beacons. The demand for this technology depends upon the cost of implementation, lower costs preferred. In cellphone application, cost should be in minor increase from existing antenna costs. Power requirements critical, for example, not drain cellphone battery as higher frequency more challenging to get signal through material such as walls. Recommend pairing this technology with a lower frequency version in an operational system. Should use a standard network as its backhaul. The current available technology has insufficient accuracy. Preference is for sub-degree accuracy. Needs to be able to change beam direction quickly. New tech more likely for first customer to be one who can make successful and who has both the access side and the client side. Work with experienced system integrator to support and install so the customer can just use it easily.

EXPERT is responsible for strategy on communication technologies. This includes developed or leading acquisitions for communication technologies that are used in their products, across all divisions. These technologies include but are not limited to wireless, satellite, phased array, etc. Company covers many industries with challenging communication environments. EXPERT has been leading product teams and commercializing solutions for over 25 years and has significant expertise in communication technologies.

Targeting any government agency will be an 18-month minimum sales cycle. Millimeter waves are not yet something well understood or experienced in much of the military and therefore may increase acceptance timeframe. Recommend first customer is non-military which gains credibility experience while in the 18-month cycle.

Note that as of February 22, 2017 ARRIS International plc has entered into agreement to purchase Brocade Communication Systems Inc.'s Ruckus Wireless and ICX Switch business. The business unit will be led by, Dan Rabinovitsj the current Ruckus COO. The acquisition is expected to close in third quarter ending July 20, 2017. [5]

We have also contacted the following end-users to gauge their views on the technology and the marketplace. In some arenas, the population of end-users is such that these end-users are also the experts. In this case, they were asked to comment from both perspectives in order to gain the necessary information.

End-User on Competitive Opening	
Name	EXPERT
Title	CEO
Organization	XX
Phone	XX
E-mail	XX
Interview notes and comments in regard to importance of the need being addressed, key specifications that may appeal to the end-users, market dynamics, competition, price	This would be more valuable if could get a position using devices such as using 4 units of the technology to compare the AOA and get the X and Y location. This would be useful for security, defense, law enforcement when paired with GPX to get omnidirectionality. Fire, rescue, police and defense could use this technology with wireless connection especially on cellphone or remote police, fire and between the devices in situations such as 'first person shooter'. One possible example would be to sell to law enforcement for set of 4 units at $5000. Until included on cellphones this would be slow sale cycle and not result high volume sales rather customized configurations. Could be useful to 'setup on the fly' as well as allow for fine tuning on cell towers.

[5]"ARRIS TO ACQUIRE RUCKUS WIRELESS AND ICX SWITCH BUSINESS" https://www.ruckuswireless.com/press/releases/20170222-arris-acquire-ruckus-wireless-and-icx-switch-business-800-million-cash (accessed March 10, 2017).

factors, and market entry strategies.	

End-User on Competitive Opening	
Name	Richard McCarrick
Title	Technical Contactor
Organization	Micro-Ant
Phone	603-389-6362
E-mail	dickmccarrick2@gmail.com
Interview notes and comments in regard to importance of the need being addressed, key specifications that may appeal to the end-users, market dynamics, competition, price factors, and market entry strategies.	Mass produced products such as cell phones have tiny form factors and specific energy requirements which both make the manufacturers loath to change anything about physical configuration due to high manufacturing volumes. If performance is 'good enough' that is typically sufficient for use in products produced by the millions. Would have to get in on the initial model design phase More likely to be able to introduce new designs into products that are made by the dozens or hundreds, as well as those where the change in form factors and energy requirements are not as critical. This may include the military, surveillance, communication, homeland security, and specialty production such as NASA and other similar applications. Most devices use omnidirectional antenna and typically don't care from where the signal is coming. An exception to this is in remote location or where spotty and insignificant signal strength. Issue also occur in where many blockages such as multitude of high rise buildings in cities where the signal gets bounced around off buildings rather than coming directly from the cell tower. Military may have need for special communication where signals are weak and need to focus in and to boost the signal. Will need better data integrity for wide bandwidth to optimized signal focus through optimal alignment of antenna to be seen as useful. Importance of antenna capabilities expands as need for bandwidth increases with increase in transfer over radio waves of images, voice and music.

In addition to providing technical writing of manuals and other content for Micro-Ant, McCarrick has worked on multiple NASA projects.

The interviewees all indicated the importance of form factor and cost compliance concerns and to expect long sales cycle. Important to show how the technology is an improvement as A-O-A perceived as an older technology. For solo opportunity, best case would be for customized designs. To get into large volume situation such as cellphones, suggest cooperative agreements and/or royalty plans with other known vendors who already have client relationships.

Given our own research and the views of the above expert and end-users, we anticipate the following parameters will be significant when this technology is evaluated by end-users. It is critical to understand engineering requirements for the primary application. If the technology

does not meet and/or exceed current requirements for **performance**, it will be difficult to commercialize.

Our Current View of End-User Requirements/Specifications			
Engineering Requirement	***Units***	***Value Desired by User***	***Why Desired***
Form factor	mm or inches	Product dependent	Must fit into existing technology especially for mass produced products such as cell phones, lower volume items may have great flexibility
Energy consumption		Product dependent	Must not drain the battery (ex. cellphone)
Heat generation		Product dependent	Must not over heat itself nor equipment built into
Radio Frequency (RF) Safety		Product dependent	Compliance with FCC[6]
Signal power		Product dependent	Range of service taking into account interference with surroundings and equipment.
Support older signals		4G LTE	Maintains additional connections to 4GLTE as well as 5G[7]

Users' abilities to buy the technologies they want are constrained by relevant federal, state, and local government regulations and by relevant standards and certification requirements. These requirements indicate test and evaluation procedures that can speed market acceptance if incorporated into concurrent engineering.

Each industry and location have their own applicable safety requirements beyond the manufacturing/assembly requirements which must be applied. As the technology changes, so do the requirements. 5G by definition is still an evolving science.

Examples of Regulations, Standards, and Certifications		
Regulatory Requirement	***Description***	***Comments***
Radio Frequency (RF) Safety	Compliance with Federal Communication Commission (FCC) compliance for various applications[8]	Ensure personal safety and lack of communication interrupts
UL product certification	Global independent safety science company[9]	Testing to standards to evaluate and manage risk.

[6] "FCC Equipment Authorization "Federal Communications Commission, https://www.fcc.gov/engineering-technology/laboratory-division/general/equipment-authorization (accessed March 20, 2017).
[7] "Smart Antennae: Critical for 5G" ABIresearach, January 13, 2016, https://www.abiresearch.com/blogs/smart-antennae-critical-5g/ (accessed March 10, 2017).
[8] FCC (Federal Communications Commission, https://www.fcc.gov/ (accessed December 14, 2017)
[9] UL (Underwirters Laboratory), http://www.ul.com/ (accessed December 14, 2017)

Finally, **price** is always a concern for new technology.

Price
Price is dependent upon application and quantity. A 4 antennas system package for security/search a price of $5000 USD. A component within a cellphone would be at a lower price (less than $5 USD)[10] and higher volume.

Specific individual component cost of antenna used within cell phone was not available from vendors. An aftermarket iPhone 6 Wi-Fi Antenna assembly had a retail purchase price of $7.95USD.[11] When purchased in massive quantities for discounted per item cost by cell phone manufacturer, the price per antenna chip even with customization and new advanced technology would be less than $5 each.

Competition

There is a range of competitive technologies to consider when comparing this technology to those on the market now, and those that may be available in a five-year window from the date of anticipated market entry. The products, services, and technology below demonstrate the range of potential substitutes from which customers will be able to choose.

We conducted a search for relevant products, patents, and projects using Google and ADD using the terms “reconfigurable antenna”, “smart antenna”, “5G”, “antenna”, “millimeter wave”, “angle-of-arrival”. Boolean operators “and” and “or” were used in combination with key words for broad to narrow searches.

Examples of Relevant Products/Services Identified			
Product Name	***Manufacturer***	***Relevance***	***Web site***
Ethertronics Active Steering™	Ethertronics Inc.	Continually optimizes the antenna’s direction in real-time on a per millisecond basis	https://www.ethertronics.com/
Aironet	Cisco	Access to technology solutions	http://www.cisco.com/
Zoneflex Access Points	Ruckus	Patented technologies to ensure consistently great performance	https://www.ruckuswireless.com/
LoRaWAN™	Semtech	Proprietary platforms used in innovative systems and products in the fastest growing markets today. These markets include smartphones, LCD TVs, notebooks, tablets, smart grid, automotive, automatic meter	http://www.semtech.com/

[10] “iPhone 6 Plus 5GHz Wi-Fi Antenna Replacement” Walter Galan, https://www.ifixit.com/Guide/iPhone+6+Plus++5GHz+Wi-Fi+Antenna+Replacement/29806 (accessed May 21, 2017).

[11] “iPhone 6 Plus 5GHz Wi-Fi Antenna Replacement” Walter Galan, https://www.ifixit.com/Guide/iPhone+6+Plus++5GHz+Wi-Fi+Antenna+Replacement/29806 (accessed May 21, 2017).

		reading, medical, wireless infrastructure, PON, Internet of Things, optical transport and datacenters.	
Frequency antenna	Trimble	For embedded positioning technologies and high dynamics	http://www.trimble.com/

Per Jeff Shamblin, CTO, Ethertronics, at the 5G innovation Summit: "Three primary differences in 5G antenna design: the interface between the antenna and the radio frequency front end; the use of arrays instead of single antennas; and reliance on beam steering. In general, antenna systems for 5G will need to support higher gain in order to maintain the same or similar range as previous technology generations. However, he noted, antenna sizes are shrinking and the ability to use arrays of small antennas does mean high gain becomes easier to accomplish. Since the antenna arrays are so small – just 3 millimeters by 3 millimeters for one antenna – it's possible for reception to be established similar to techniques used by the military in aircraft: by placing multiple arrays in, say, the four corners of a device. However, the small size of each antenna also means much tighter requirements for precise manufacturing, as tiny errors can throw off the ability of such small antennas to function properly."[12]

Existing leading antenna companies include: Accel Networks LLC, Airgo Networks Inc., Airnet Communications Corp, Alcatel-Lucent International Holdings Inc., ArrayComm LLC, Bandspeed Inc, Bell Labs, Broadcom Corp, California Amplifier Inc., Cobham Antenna Systems, CommScope, eTenna Corp, Exelis Inc., Intel Corp, Jiashan Jinchang Electronics Co., Ltd., Kyocera Corporation, L-3 Communications Holdings Inc., Linx technologies, Lockheed Martin Corporation, Lucent technologies, Magnolia Broadband, Inc, Molex, Motorola Inc., Nortel Networks Corp., Philips Semiconductor, Qualcomm Inc., Raytheon Company, Ruckus Wireless., Samsung Electronics Co Ltd., SiBEAM Inc., Sofant Technologies, and Thales SA.[13,14,15,16]

[12] "Everything is different for 5G antennas" by Kelly Hill, December 6, 2016, http://www.rcrwireless.com/20161206/test-and-measurement/everything-is-different-for-5g-antennas-tag6 (accessed March 10, 2017).

[13] "Smart Antenna Market - Global Industry Analysis, Size, Share, Growth, and Forecast 2015 - 2023: Transparency Market Research", Transparency Market Research, October 21, 2015, https://globenewswire.com/news-release/2015/10/21/778537/10153555/en/Smart-Antenna-Market-Global-Industry-Analysis-Size-Share-Growth-and-Forecast-2015-2023-Transparency-Market-Research.html (accessed May 21,2017).

[14] "Global Antenna Market - By Type (Radio Antennas, Smart Antennas), Technology (SIMO, MIMO, MISO), Application, Industry, Geography, Trends, Forecast - (2017 - 2022)", Mordor Intelligence, January 2017, https://www.mordorintelligence.com/industry-reports/antenna-market (accessed May 21, 2017).

[15] "Smart Antenna Market (Switched Multibeam Antenna and Adaptive Array Antenna) analysed by SIMO (Single Input Multiple Output), MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output) for Wi-Fi, WiMax, Cellular, and RADAR systems - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 – 2023" Transparency Market Research, January 7, 2016, http://www.transparencymarketresearch.com/smart-antenna.html (accessed May 21, 2017).

[16] Markets and Markets, "Antenna Transducer and Radome (ATR) Market by Product (Antenna, Transducer, and Radome), by Application (Defense, Aerospace and Homeland Security), by Technology (Radar, Communication and Sonar), by Cost - Analysis & Global Forecasts to 2020". http://www.marketsandmarkets.com/Market-Reports/antenna-transducer-radome-market-58948192.html (accessed December 12, 2016).

We search the following data sets: *INPADOC*, which contains patent family documents from 71 world patent signatories and legal status information from 42 patent offices; *WIPO PCT Publications*, which contains abstracts, full document images, and full text from over a hundred member countries of the Patent Cooperation Treaty; *European Patents and Applications* from the European Patent Office; and *US Patents and Applications* from the US Patent and Trademark Office. Searching these data sets simultaneously often does lead to multiple counts of the same patent, as both the application and patent may be retrieved or the item can show up in multiple databases. This procedure highlights applicants who file, pursue the patent, and protect it in multiple jurisdictions and the presumption is a patent protected in multiple jurisdictions is more important to its owners than one which is not.

Given this procedure, the patents below were found using the following search string. Overall, the string produced hits.

Search String	Number of Hits
"reconfigurable antenna"	322
"reconfigurable antenna" AND 5G	7
"reconfigurable antenna" AND "angle-of-arrival"	1
"reconfigurable antenna" AND "millimeter wave"	37
"5G antenna"	6
"smart antenna"	2117

The following patents and patent applications indicate kinds and range of technology that show up in the patent literature. We emphasize that we look at patents from the standpoint of market competition. We have no opinion on the patentability of your technology. Please consult with qualified legal counsel for opinions on client's freedom-to-operate and extent of Intellectual Property protection. Material in quotes is from the patent abstract unless otherwise noted.

Examples of Relevant Patents and Patent Applications Identified				
Patent or Patent Application Number	***Patent Title***	***Date***	***Relevance***	***Assignee***
20160314602	Multi-sensor compressive imaging	October 27, 2016	Multi-sensor compressive imaging systems can include an imaging component and an auxiliary sensing component to identify the location or posture of an imaging target	Duke university
US 9,479,266	Quasi-optical coupler	October 25, 2016	A quasi-optical coupling system launches and extracts surface wave communication transmissions from a wire. At millimeter-wave frequencies, where the wavelength is small compared to the macroscopic size of the equipment, the millimeter-wave transmissions can be transported from one place to another	AT&T Intellectual Property I, L.P.

			and diverted via lenses and reflectors, much like visible light.	
US 9,466,885	Reconfigurable antenna	October 11, 2016	A method and apparatus for a reconfigurable antenna	Qualcomm Incorporated
US 9,461,682	Method and system for filtering out adjacent frequency band interference	October 4, 2016	A method and system for filtering out adjacent band interference using control module filters to change antenna structure.	ZTE Corporation
US 9,445,290	Method for problematic user detection	September 13, 2016	Management of wireless communication networks and, more particularly, to methods, apparatuses and systems for spectrum management, load balancing and problematic station detection featuring problematic station detection algorithms and includes solutions for optimizing wireless network management.	Go Net Systems LTD
20160286407	A network node and method for adjusting antenna parameters in a wireless communications	September 29, 2016	A network node and a method performed by a network node for adjusting antenna parameters of one or more antennas in a wireless telecommunications network. Determines signal strength value difference from two antennas that passes a determined threshold for the signal strength value difference, and adjusts at least one antenna parameter of at least one of the two antennas.	Elefonaktieb Olaget L M Ericsson
20160197644	Dynamically configurable antennas	July 7, 2016	A dynamically configurable antenna is integrated into a system configured to transmit and receive data. Antenna control software and/or hardware configures the antenna to transmit and receive data with different operating characteristics, depending on the communication needs of the system.	Autodesk, Inc.
US 9,236,955	Reconfigurable antennas for performance enhancement of interference networks employing interference alignment	January 12, 2016	Using reconfigurable antenna based pattern diversity, to realize an optimal channel in order to maximize the distance between two subspaces, thereby increasing sum-rate. Show the benefits of pattern reconfigurability using real-world channels, measured in a MIMO-OFDM interference network with the results are quantified with two different reconfigurable antenna architectures.	Drexel University & The Trustees of the University of Pennsylvania

US 8,912,957	Reconfigurable millimeter wave multibeam antenna array	December 16, 2014	A reconfigurable millimeter wave multibeam antenna array that includes a first millimeter (MM) wave antenna, a second MM wave antenna, and a hybrid coupler coupled to the first and second MM wave antennas.	Qualcomm Incorporated

The evolving 5G technology was not a primary focus mentioned in these patents. Smart antennas are receiving more attention in a variety of applications. These several recent patents for reconfigurable antennas using a variety of methods beyond AOA. Other technologies under are research and develop may become competition within the next few years.

The imaging patents listed above are included to provide parallel market information.

Examples of Relevant R&D/ Clinical Projects Identified			
Project Title	***Performing Institution***	***Performance Period***	***Relevance***
Directional Cell Search for Millimeter Wave Cellular Networks	NYU Wireless	2015	Analyses of the problem of initial cell search. Cell search is the process by which a mobile device discovers a base station to initiate communication. Developing fast cell search methods is particularly challenging in the mmWave range due to the need to scan for initial directions of communication using very narrow beams. We show that a low-power fully digital architecture can offer dramatically faster initial search than current sequential beam search methods. These results can have dramatic benefits for reducing latency, improving handover and enabling greater use of idle modes for low-power consumption.[17]
Path Loss Models for 5G Millimeter Wave Propagation Channels in Urban Microcells	NYU Wireless	2013	Measurements for future outdoor cellular systems at 28 GHz and 38 GHz were conducted in urban microcellular environments in New York City and Austin, Texas, respectively. Measurements in both line-of-sight and non-line-of-sight scenarios used multiple combinations of steerable transmit and receive antennas.[18]
A novel adaptive beamforming algorithm for a	Sch. of Electr. & Comput. Eng., Hanyang Univ., Seoul,	2000	A novel adaptive beamforming algorithm for a smart antenna system in a CDMA mobile communication environment approximating the autocorrelation matrix with the instantaneous signal vector at each snapshot. The required

[17] Barati, Hosseini, Rangan, Liu, Korakis, Ranwar, Rappaport, "Directional Cell Search for Millimeter Wave Cellular Networks" NYU Wirelss, IEEE Transactions on Wireless Communications Vol. 14 Issue 12, July 2015. http://ieeexplore.ieee.org/document/7161389/ (accessed November 7, 2016).

[18] MacCartney, G.R., Zhang, J., Nie, S., Rappaport, T.S., "Path Loss Models for 5G Millimeter Wave Propagation Channels in Urban Microcells", IEEE Global Communication, http://wireless.engineering.nyu.edu/wp-content/uploads/2013/12/Path-Loss-Models-for-5G-Millimeter-Wave-Propagation-Channels-in-Urban-Microcells.pdf (accessed January 6,2017).

smart antenna system in a CDMA mobile communicatio n environment	South Korea		condition on the adaptive gain for the proposed algorithm to converge is derived analytically. The proposed beamforming algorithm is applied to the base station of a code-division-multiple access (CDMA) mobile communication system.[19]
Ultra Wideband Systems with MIMO	Leibniz University of Hannover, Germany	2010	Thomas Kaiser, Feng Zheng's book includes information on coarse function of AoA mapping (multiple-input multiple-output)[20]
Smart antennas	Dept. of Electr. & Comput. Eng., Democritus Univ. of Thrace, Xanthi, Greece	2000	Smart antennas for improving the performance of wireless radio systems: to enhance the received signal, suppress all interfering signals, and increase capacity. Provides a basic model for determining the angle of arrival for incoming signals, the appropriate antenna beamforming, and the adaptive algorithms that are currently used for array processing, shown how smart antennas with spatial processing provide improvement.[21]
A Polarization-Reconfigurable Filtering Antenna System	Nanyang Technological University, Singapore	2013	Antenna system with polarization-reconfigurable filtering (PRF) antenna elements that can adapt to various propagation conditions electronically, and consequently achieves polarization-match with the incoming electromagnetic waves. Also, it has intrinsic filtering capability so no additional filter circuit is required.[22]
Optimal detector randomization in cognitive radio systems in the presence of imperfect sensing decisions	Department of Electrical Engineering & Computer Science, Syracuse University	2013	Optimal detector randomization is developed for secondary users in a cognitive radio system in the presence of imperfect spectrum sensing decisions. It is shown that the minimum average probability of error can be achieved by employing no more than four maximum a-posteriori probability (MAP) detectors at the secondary receiver.[23]
Efficient Channel Estimation for	Department of Electrical and Computer	2016	Multifunctional and reconfigurable multiple-input multiple-output (MR-MIMO) antennas capable of dynamically changing the operation frequencies, polarizations and radiation

[19] Choi, Shim, "A novel adaptive beamforming algorithm for a smart antenna system in a CDMA mobile communication environment", IEEE Transactions on Vehicular Technology Vol. 49, Issue: 5, Sep 2000. http://ieeexplore.ieee.org/document/892584/ (accessed December 8, 2016).

[20] Thomas Kaiser and Feng Zheng, Ultra Wide Systems with MIMO (Chichester, UK: Wiley, 2010)

[21] M. Chryssomallis, "Smart antennas", IEEE Antennas and Propagation Magazine Vol. 42, Issue: 3, Jun 2000, http://ieeexplore.ieee.org/document/848965/ (accessed December 8, 2016).

[22] Gan, Yang, Tan, Lim, Huynh, and Mayank, "A Polarization-Reconfigurable Filtering Antenna System" IEEE Education 2013 Student Design Contest Winning Papers, http://www.ieeeaps.org/images/aps-pdf/2013StudentWinner1.pdf (accessed December 8, 2016).

[23] Sezer, A. D., Gezici, S., & Gursoy, M. C. (2014). Optimal detector randomization in cognitive radio systems in the presence of imperfect sensing decisions. IEEE Communications Letters, 18(2), 213-216. [6697912]. DOI: 10.1109/LCOMM.2013.120713.132423, https://experts.syr.edu/en/publications/optimal-detector-randomization-in-cognitive-radio-systems-in-the, (accessed January6, 2017).

Reconfigurable MIMO Antennas: Training Techniques and Performance Analysis	Engineering, Utah State University		patterns, can enhance system capabilities. However, using MRMIMO antennas with a large number of operational modes may incur prohibitive complexity due to the need for channel state estimation for each mode requiring deriving explicit relation among the radiation patterns for the antenna modes and the resulting channel gains. Propose a joint channel estimation/prediction scheme where only a subset of all the antenna modes is trained for estimation, and untrained used for the correlations among the different antenna modes.[24]
Flexible millimeter-wave frequency reconfigurable antenna for wearable applications in 5G networks	School of Electronic Engineering and Computer Science, Queen Mary University of London	2016	Millimeter-wave (MMW) antennas for the fifth generation (5G) networks which integrate the frequency reconfigurability in a flexible antenna operating at MMW frequency spectrum.[25]
Pattern reconfigurable millimeter-wave antenna design for 5G handset applications	Department of Electrical Engineering, National Taiwan University of Science and Technology	2016	Pattern reconfigurable antenna operating in the 36~40 GHz band to be used on handheld devices for future 5G wireless communications. A multi-antenna system comprised of a reconfigurable power divider that excites one or multiple antennas according to system's commands.[26]
Energy efficient cloud radio access network with a single RF antenna	The University of Edinburgh	2016	The cloud radio access network (C-RAN) energy efficiency (EE), consisting of multiple remote radio heads (RRHs) equipped with electronically steerable parasitic array radiator (ESPAR) antennas, which provide multiple antenna functionality with a single radio frequency (RF) chain. An EE optimization is formulated to obtain the configuration of ESPAR and the closed-form expressions of the voltage feeding and the loadings are derived for signal transmission at each RRH.[27]
Small-Size Reconfigurable	Shanghai University	2016	A small-size reconfigurable loop antenna for mobile phone applications with a compact volume of 55 × 5 × 3 mm^3To

[24] Bahceci, Hasan, Duman, Cetiner, "Efficient Channel Estimation for Reconfigurable MIMO Antennas: Training Techniques and Performance Analysis," IEEE Transactions on Wireless Communications Vol. PP, Issue: 99 November 2016. http://ieeexplore.ieee.org/document/7738578/ (accessed December 8, 2016).
[25] Jilani, Greinke, Hao, Alomainy, "Flexible millimetre-wave frequency reconfigurable antenna for wearable applications in 5G networks", 2016 URSI International Symposium on Electromagnetic Theory, August 2016. http://ieeexplore.ieee.org/document/7571536/ (accessed December 9, 2016).
[26] Chang, Yang, Chang, Liao, Cho, Chen, "Pattern reconfigurable millimeter-wave antenna design for 5G handset applications", 2016 10th European Conference on Antennas and Propagation, April 2016. http://ieeexplore.ieee.org/document/7481321/ (accessed December 9, 2016).
[27] Zhou, Ratnarajah, Xue, Khan, "Energy efficient cloud radio access network with a single RF antenna," 2016 IEEE International Conference on Communications, May 2016, http://ieeexplore.ieee.org/document/7511045/ (accessed December 9, 2016).

Loop Antenna for Mobile Phone Applications			cover more operating bands with such compact antenna volume, the reconfigurable technique is therefore applied by inserting an RF switch at the end of the proposed antenna to improve bandwidth at the low band. [28]
Millimeter-wave frequency reconfigurable T-shaped antenna for 5G networks	School of Electronic Engineering and Computer Science, Queen Mary University of London	2015	Millimeter-wave reconfigurable antennas are predicted as a future of next generation wireless networks with the availability of wide bandwidth. A coplanar waveguide (CPW) fed T-shaped frequency reconfigurable millimeter-wave antenna for 5G networks is presented for wireless systems operating in narrow passages, corridors, mine tunnels, and person-to-person body centric applications.[29]
Reconfigurable transmitarray antennas at millimeter-wave frequencies	Universit´e Rennes	2015	Transmitarray antennas of interest for millimeter-wave wireless and radar applications where a high radiation gain is needed. They are based on a thin multi-layer array of transmitting unit-cells focusing/collimating the radiation to/from one or several focal sources by locally tuning the phase of the transmitted signals. Each unit-cell includes at least three functions: receiving, phase shifting and transmitting the signal. Some promising applications are in the field of radar systems, satellite communications and next-generation wireless metropolitan area networks.[30]

In the book "Ultra Wideband Systems with MIMO" Coverage of the research on combining UWB Systems with multiple antennas includes 'the geometric or parametrerized approach – the position of the target is associated with the received-signal-strength (RSS), angel-of-arrive (AoA) or ToA of the received signal at the sensor and solved from the RSS, AoA and/or ToA information."[31]

Over the next few years, Nokia expects a 10,000x increase in bandwidth. Today's 4G LTE wireless networks simply can't handle the data demands of our rapidly approaching, hyperconnected future whether it be enhanced mobile broadband and ultra-reliable machine to machine communications.[32]

Competitive Landscape
Smart antenna market is growing. Proof of advanced technology and liaisons with related/integrated vendors will be required to make in-roads into specific markets.

[28] Wang, Wang, Wu, Chen, Wu, Sim, Yang, "Small-Size Reconfigurable Loop Antenna for Mobile Phone Applications",

[29] Jilani, Abbas,Esselle, Alomainy, "Millimeter-wave frequency reconfigurable T-shaped antenna for 5G networks", https://www.computer.org/csdl/proceedings/wimob/2015/7701/00/07347946.pdf (accessed December 12,2016).

[30]Luca Di Palma, "Reconfigurable transmitarray antennas at millimeter-wave frequencies", HAL 2016, https://tel.archives-ouvertes.fr/tel-01308275/file/DI_PALMA_Luca.pdf (accessed December 12, 2016)

[31] Thomas Kaiser, Feng Zheng, "Ultra Wideband systems with MIMO" (Wilthsire: John Wiley, March 2010) page 112.

[32] "Wireless Communications: The Rise of 5G", National Instruments, February 22, 2017, http://forums.ni.com/t5/NI-Blog/Wireless-Communications-The-Rise-of-5G/ba-p/3586929 (accessed May 17, 2017).

Market

While market sizes are hard to estimate, the following provides an example of how to figure out the total addressable market for this technology. While we seek to be as accurate as feasible in the estimate below, it is budget constrained and thus preliminary. We estimate the total market size, at saturation, for Global, and for all competitors, to be approximately:

Market Niche Size			
Market Size in Dollars	***Growth Rate***	***Base Year***	***Detailed Basis for Estimate***
$1.43 billion (global chip antenna market)	13.1%	2016	According to a new market research report on chip antennas, the market for the same is expected to be worth USD 2.99 billion by 2022, growing at a CAGR of 13.1% between 2016 and 2022. The chip antenna market grows due to the increasing demand for chip antennas in IoT devices for wireless communication yet be constrained by performance efficiency and a limited range. The dielectric chip antenna, the largest share in the market in 2015, continues in high demand for compact size due to constraints in consumer electronic devices such as smartphones, tablets, laptops, smart TVs, gaming consoles, and wearables applying wireless applications such Bluetooth, WLAN/WiFi, and GPS.[33] Military communications systems, equipment and services are vital components meaning that investment and development of communications capacity and technological expansion will continue over the next decade. Visiongain has calculated that in 2014 the market will be worth $16.35bn.[34] Of the Smart antenna market regions, North America held the largest market share of 30.4% in 2014, followed by Europe and together held more than 50% of the global smart antenna market in 2014. Asia Pacific is projected to be the fastest growing region during 2015-2023. The global smart antenna market is likely to be worth US$30.12 bn by the end of 2023 as compared to US$14.72 bn in 2014 and is projected to grow at a CAGR of 8.5% between 2015 - 2023. The replacement of laptops and other personal digital assistants (PDAs) by smartphones that offer GPS, high data processing abilities, internet applications,

[33] "Chip Antenna Market by Product Type (Dielectric Chip and LTCC Chip), Application Type (WLAN/WiFi, Bluetooth/BLE, Dual Band/Multi-Band, and GPS/GNSS), End-User Industry (Automotive, Healthcare, and Industrial & Retail) - Global Forecast to 2022", Global Information Inc., https://www.giiresearch.com/report/mama372019-chip-antenna-market-by-product-type-dielectric.html, accessed May 21,2017).

[34] "Military Communications Report 2014-2024", Global Information, Inc., https://www.giiresearch.com/report/kt300763-military-communications-report.html (accessed May 21, 2017).

			and multimedia functionality are expected augment the sales of smartphones.[35]

"The antenna, transducer, and radome (ATR) market is estimated to be USD 7.91 Billion in 2015, and is projected to reach USD 12.48 Billion by 2020, at a CAGR of 9.53% from 2015 to 2020."[36]

The global antenna market is expected to reach USD 11.31 billion by 2020 at a projected CAGR of 9.27% over the period of 2015-2020. As demand for wireless systems and wireless communications increases so too the demand for antennas. Smart antennas are antenna arrays that use smart signal processing algorithms to identify spatial signal signature such as the direction of arrival of the signal. Smart antenna techniques are used in RADAR, radio communication, and cellular networks.[37]

"A Scottish firm, Sofant Technologies, has developed a miniature "smart" Wi-Fi antenna for mobile devices and has secured more than GBP 1.5 million in European funding to help it take its technology to the market."[38]

Market Niche Summary	
Name	Smart, direction finding, reconfigurable chip antenna
Basis for Feasibility in Niche	Smart antennas used in wireless communication and smart phones (cellular) and technological applications. Enhancing capability of range, capacity and coverage and rising applications in technologies such as ultra wideband and radio frequency identification are the key factors[39]

[35] "Smart Antenna Market (Switched Multibeam Antenna and Adaptive Array Antenna) analysed by SIMO (Single Input Multiple Output), MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output) for Wi-Fi, WiMax, Cellular, and RADAR systems - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 – 2023", Transparency Market Research, January 7, 2016, http://www.transparencymarketresearch.com/smart-antenna.html (accessed May 21, 2017).

[36] "Antenna, Transducer, and Radome Market", Markets and Markets, November 2015, http://www.marketsandmarkets.com/Market-Reports/antenna-transducer-radome-market-58948192.html?gclid=Cj0KEQjwmIrJBRCRmJ_x7KDo-9oBEiQAuUPKMvva_FL-QJnYVDHACfKNThiCGoNzNiJI1AQx_B7pEowaApu98P8HAQ (accessed May 21,2017).

[37] "Global Antenna Market - By Type (Radio Antennas, Smart Antennas), Technology (SIMO, MIMO, MISO), Application, Industry, Geography, Trends, Forecast - (2017 - 2022)", January 2017, Mordor Intelligence, https://www.mordorintelligence.com/industry-reports/antenna-market (accessed May 21, 2017).

[38] "Global Antenna Market - By Type (Radio Antennas, Smart Antennas), Technology (SIMO, MIMO, MISO), Application, Industry, Geography, Trends, Forecast - (2017 - 2022)", Mordor Intelligence, January 2017, https://www.mordorintelligence.com/industry-reports/antenna-market (accessed May 21, 2017).

[39] "Smart Antenna Market (Switched Multibeam Antenna and Adaptive Array Antenna) analysed by SIMO (Single Input Multiple Output), MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output) for Wi-Fi, WiMax, Cellular, and RADAR systems - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 – 2023", Transparency Market Research, January 7, 2016, http://www.transparencymarketresearch.com/smart-antenna.html (accessed May 21, 2017).

Likely Market Drivers Which Can Affect the Market Size and Market Share for the New Technology	Increasing demand for smart antennas in wireless communication: Wireless microphones, Bluetooth devices, wireless computer networks, and RFID tags (used for security purposes) are the major systems/devices that use antennas.[40] Increasing application of smart antennas in smart phones that offer GPS, high data processing abilities, internet applications, and multimedia functionality are expected replace laptops and PDAs.[41] Technology advancements in cellular networks[42] Smart antennas are more powerful, efficient, and cost effective by enhancing the capability of coverage, range, and capacity. The global market for smart antennas is expected to grow at a significant rate due to increasing applications of wireless technology in mobile communication and defense. There is a growing need for faster data transmission with web browsing, high speed downloading, and optimized evolution data, radio frequency identification, ultra wideband, mobile direct broadcast satellite, DBS wireless network areas (WLANs), mobile phones, and WiMax. Due to poor quality "last miles" connection and signals transmission, copper wires and traditional methods are being replaced by wireless antennas.[43] Defense: Improvements in sonar and sensor technologies boost the market for defense transducers, and modernization programs for defense antennas with key driving factors influencing the growth of the antenna, transducer, and radome market. Operational efficiency and inadequate testing facilities for radomes, and budgetary constraints are restrict the growth of this market. Replacement and upgrades of submarines offers new market growth opportunities in the global ATR market.[44]
Anticipated End-User Criteria	Form factor of technology must fit into configuration (ex: cellphone, medical, security equipment)

[40] "Global Antenna Market - By Type (Radio Antennas, Smart Antennas), Technology (SIMO, MIMO, MISO), Application, Industry, Geography, Trends, Forecast - (2017 - 2022)", January 2017, Mordor Intelligence, https://www.mordorintelligence.com/industry-reports/antenna-market (accessed May 21, 2017).
[41] "Smart Antenna Market (Switched Multibeam Antenna and Adaptive Array Antenna) analysed by SIMO (Single Input Multiple Output), MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output) for Wi-Fi, WiMax, Cellular, and RADAR systems - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 – 2023", Transparency Market Research, January 7, 2016, http://www.transparencymarketresearch.com/smart-antenna.html (accessed May 21, 2017).
[42] "Smart Antenna Market (Switched Multibeam Antenna and Adaptive Array Antenna) analysed by SIMO (Single Input Multiple Output), MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output) for Wi-Fi, WiMax, Cellular, and RADAR systems - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 – 2023" Transparency Market Research, January 7, 2016, http://www.transparencymarketresearch.com/smart-antenna.html (accessed May 21, 2017).
[43] "Smart Antenna Market - Global Industry Analysis, Size, Share, Growth, and Forecast 2015 - 2023: Transparency Market Research", Transparency Market Research, October 21, 2015, https://globenewswire.com/news-release/2015/10/21/778537/10153555/en/Smart-Antenna-Market-Global-Industry-Analysis-Size-Share-Growth-and-Forecast-2015-2023-Transparency-Market-Research.html (accessed May 21,2017).
[44] "Antenna, Transducer, and Radome Market", Markets and Markets, November 2015, http://www.marketsandmarkets.com/Market-Reports/antenna-transducer-radome-market-58948192.html?gclid=Cj0KEQjwmIrJBRCRmJ_x7KDo-9oBEiQAuUPKMvva_FL-QJnYVDHACfKNThiCGoNzNiJI1AQx_B7pEowaApu98P8HAQ (accessed May 21,2017).

	Cost effective increased efficiency, power and range Support higher gain
Initial Impression of Adequacy of Current Technology to Address those Needs	Identify specific market to approach and work with a known partner in that expertise area rather than trying to approach high volume manufacturer such as cellphone manufacturing. Have specifics as to how this unique approach will contribute so can get beyond concept that is old technology.
Cost or Price of Current Technology	Per item chip less than $5 Determine licensing agreement with vendor(s)
Generally Applicable Market Entry Barriers	Form factor within such as cellphones and high volume Fitting in and standing out with the existing leading antenna companies Higher cost of deployment is major inhibitor[45]

Cisco forecasts that by 2020, 5.5 billion people will own mobile phones. With data-hungry applications including 4K video, driverless vehicles, smart factories, and broadband access expanding to the most rural places on Earth, will need increased data rates, expanded network capacity, and improved reliability, which advances the need for 5G cellular networks for wireless communications.[46]

The antenna, transducer, and radome (ATR) market is estimated to be USD 7.91 Billion in 2015, and is projected to reach USD 12.48 Billion by 2020, at a CAGR of 9.53% from 2015 to 2020. Markets include defense, aerospace, security including radar, communication, sonar[47].

According to Joe Hoffman of ABI Reseach, the 5G Network coming to mobile broadband will generate new network operating models and infrastructure for networks in unlicensed and shared licensed spectrum. The nature of 5G frequencies will change the design and operation of cellular networks. “Obtaining stronger signals with 5G involves smarter antenna technology, more radio spectrum, and smaller cells. The physics of 5G spectrum changes the economics for antenna solutions, as the higher frequencies equate to packing more antennae into a smaller space and remaining cost effective.” [48]

[45] “Smart Antenna Market - Global Industry Analysis, Size, Share, Growth, and Forecast 2015 - 2023: Transparency Market Research”, Transparency Market Research, October 21, 2015, https://globenewswire.com/news-release/2015/10/21/778537/10153555/en/Smart-Antenna-Market-Global-Industry-Analysis-Size-Share-Growth-and-Forecast-2015-2023-Transparency-Market-Research.html (accessed May 21,2017)

[46] “University of Bristol and Lund University Partner With (National Instruments) NI to Set World Records in 5G Wireless Spectral Efficiency Using Massive MIMO”, http://sine.ni.com/cs/app/doc/p/id/cs-17101 (accessed December 12, 2016).

[47] Markets and Markets, “Antenna Transducer and Radome (ATR) Market by Product (Antenna, Transducer, and Radome), by Application (Defense, Aerospace and Homeland Security), by Technology (Radar, Communication and Sonar), by Cost - Analysis & Global Forecasts to 2020”. http://www.marketsandmarkets.com/Market-Reports/antenna-transducer-radome-market-58948192.html (accessed December 12, 2016).

[48] Joe Hoggman, “Smart Antennae: Critical for 5G”, January 13, 2016, https://www.abiresearch.com/blogs/smart-antennae-critical-5g/ (accessed January 6, 2017).

As the markets grows, so will the need for small scale proven technologies improving signal access. To date the 5G signals experience more interrupts when direct path is not available so finding the best path through technologies such as AoA may become more relevant. The perceptions of AoA as an old perhaps not relevant technology may hinder acceptance. Proof of concept and application will be critical. Developing relationships with manufactures and equipment supply vendors for licensing will be imperative to support acceptance into new designs. The lead time from concept to purchase will be long as will the importance of physical fit and low costs according to the interviewees.

Antennas that are able to adjust to the signals will increase the effectiveness and capacity useful for the increased cellphone volume and application requirements as well as defense and security markets. It will be key to work with antenna vendors and end product manufacturers research and development as well as with those developing the 5G standards. Showing the unique and effective contributions of the subject technology will be critical to be seen as part of the new wave functionality rather than the application of an outmoded technology. Wearables and medical markets have their own unique requirements for future development considerations.

The following venues can be used for additional market intelligence gathering and communication with potential end-users and targets.

Examples of Organizations, Meetings, and Publications to Use for Networking, Promotion, and Competitive Intelligence			
Organization	***Utility***	***Point of Contact***	***Phone Number & E-mail or URL***
IEEE Antennas & Propagation Society	Antenna analysis, design, development, measurement, and testing; radiation, propagation, and the interaction of electromagnetic waves with discrete and continuous media, etc. Networking and journals.	CJ Reddy (Vice Chair, Industrial Initiatives, IEEEAPS cjreddy@appliedem.com	IEEE.org 732 562 5501 http://www.ieeeaps.org

Entry Strategy

Using the data we have collected, we now turn to the question of how to accomplish market entry in order to sell the technology to end-users. The goal of this section is to identify the market entry barriers and develop approaches for their removal

1.1 Objectives

Identify market niches for which the technology is most appropriate and vendors with whom licensing relationships may be established to incorporate the technology into systems within each key niche.

1.2 Advantages

According to an associate professor in Syracuse University's College of Engineering and Computer Science, when moving to higher frequencies the transmission range gets shorter, unable to penetrate walls as easily and line-of-site else loss of attenuation in the signal. Smaller cell/portable base station microcells require smaller and more antennas packed into devices enabling directional transmissions to steer the signal.[49] The subject technology's ability to dynamically adjust contributes to resolving these difficulties.

The expansion into higher frequencies provides larger availability and higher transfer rates for near perfect video streaming and real-time gaming with reduced clutter and high immunity to jamming and interference. They are susceptible to restrictions due to foliage, atmospheric absorption and scatter (rain/fog), line of sight issues, and brightness temperature as absorb high frequency electromagnetic radiation that then degrades the receiver antenna performance.[50] Finding a way to address these concerns would be a major contribution.

Antennas that can find and adjust the signal direction are needed. 5G will open the door to non-traditional network operators and infrastructure in unlicensed and shared licensed spectrum. The lower numbered frequencies reach farther and cover more area for less cost than the higher numbered frequencies. Cell sites using the lower numbered frequencies will be over-subscribed, causing slow data rates and delivering a poor user experience. Smarter antenna systems will also improve network performance and capacity beyond what is capable with today's standard 2x2 and 4x4 MIMO deployments in 4G LTE. Obtaining stronger signals with 5G involves smarter antenna technology, more radio spectrum, and smaller cells. [51]

1.3 Obstacles

At first glance, Angle of Approach is considered an older technology which indicates the need for proof of applicable concept. The difficulties are encountered by 5G signals when not a clear path (such as in and around buildings) may be a relevant place to start discussions. The importance application such as triangulation to find an unknown source/location is another aspect that may be useful.

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[49] Larry Greenemeier, "5G Wireless? Wireless companies want next-generation gadgets to download at rates of gigabits per second. The question is how to make it happen," Scientific American, June 23, 2015, https://www.scientificamerican.com/article/will-millimeter-waves-maximize-5g-wireless/ (accessed January 6, 2017.)

[50] "Millimeter waves: How we got here, the physical challenges, and 5G opportunities", Nutaq of NuRan Wirless, http://www.nutaq.com/blog/millimeter-waves-how-we-got-here-physical-challenges-and-5g-opportunities (accessed January 6, 2017).

[51] "Smart Antennae: Critical for 5G" ABIresearach, January 13, 2016, https://www.abiresearch.com/blogs/smart-antennae-critical-5g/ (accessed March 10, 2017).

The technology must comply with specific and often unique form factors including size, heat, power requirements in order to be considered.

Even once a licensing relationship is established, the sales cycle of the actual product will be long, in addition to still evolving 5G design itself.

International markets may become more challenging due to political conditions and security concerns.

1.4 Strategy

In addition to finding the signal direction, the antenna also needs to be multi-connective for when the high frequency signal is blocked or unavailable.[52]

Approach known vendors (see those identified above) to pursue licensing relationships.

Target

The target is the organization(s) that will partner with the client to commercialize this technology. There are feasible and viable targets. Feasible targets have relevant product lines and appear to have an established presence in the market. In short, they are probably worth checking out to see if they make good candidates for partnering. We seek viable targets that appear to be in good financial health, are established in the market with a relevant product line, can provide capabilities that are relevant for commercializing this technology, and possess good absorptive capacity.[53] Viable targets, unless otherwise noted, are those that still appear to be good candidates after we have spoken to them on the phone to confirm their potential interest in this technology.

We cold called several targets to assess interest in this intellectual asset package. We presented this technology's attractiveness as follows: This technology is a reconfigurable radio direction finder antenna technology that estimates the angle-of-arrival (AOA) of radio signal using receiver and antenna system which estimates the low resolution of the AOA, then simulates the high-resolution estimate of AOA which is then used for the steering/reconfiguring the antenna.

We begin with examples of at least one viable target and then provide a way to find other likely feasible targets. The following table summarizes key information on an identified viable target.

[52] Joe Hoggman, "Smart Antennae: Critical for 5G", January 13, 2016, https://www.abiresearch.com/blogs/smart-antennae-critical-5g/ (accessed January 6, 2017).

[53] Absorptive capacity measures the degree to which the potential partner's staff has the scientific and engineering education and know-how to help commercialize this technology without having to "come up to speed" on generic technical issues.

Target Profile	
Name of Target and Relevant Unit	TARGET
Address of Unit	XX
Point of Contact in Target with Position	XX
Phone of Point of Contact	XX
E-Mail of Point of Contact	XX
Current Customer Base	$ 42.4 billion in sales
Target's Reason for Interest	Increased capabilities
Example of Prior Acquisition of Technology from the Outside, if Relevant	Not available
Criteria Likely to be Used to Evaluate This Technology	Form factor – size, heat, power Actual capabilities of technology in comparison to other technologies
Likely Information Desired	Form factor – size, heat, power Actual capabilities of technology in comparison to other technologies
Anticipated Time to Decision from Initial Expression of Serious Interest	Dependent upon the technology proof of concept and actual application
Name, Title, Phone, and E-mail of Likely Champion for Technology in Target if One can be Suggested	XX
Likely Preferred Legal Structure for Deal	Licensing or purchase depending upon specifics
At What Stage in Maturity does the Target Prefer to Obtain Technology	Interested in speaking with inventors now.
Will the Target Participate in Concurrent Engineering or Test and Evaluation	Yes. Interested in beta testing.
Who is the Ultimate Decision-Maker(s)	management team

We recommend that you contact the target listed above as soon as possible. Even if you feel that your technology is not mature enough at this time to pursue partnerships, it is important to establish lines of communication and keep them open so as not to lose out on an opportunity for partnering.

We have also contacted the following companies.

Other Potential Targets

Name of Company or Unit	***Address, Web site***	***Reason for Recommending***	***Name, Title, Phone, and E-mail of Point of Contact***
Qualcomm Inc.	Qualcomm Incorporated 5775 Morehouse Drive San Diego, CA 92121 USA https://www.qualcomm.com/	Tiny smart antenna	Mathew S. Grob Chief Technology Officer 858-658-4434 mgrob@qti.qualcomm.co
Cobham	Cobham Antenna Systems Lambda House, Cheveley, Newmarket, Suffolk CB8 9RG, UK Antenna Systems - Fullerton Cobham Antenna Systems, 577 Burning Tree Road, FULLERTON, California, USA 92833 www.cobham.com	Antenna systems, communications and connectivity in aerospace, avionics, satellite, radio, wireless and mobile.	Robert Urban, Sr Director, IMO Integration, Cobham Advanced Electronic Solutions 215-996-2000 robert.urban@cobham.co
Raytheon	Raytheon Company, 870 Winter Street, Waltham, MA 02451 Raytheon Advanced Products Center – Texas http://www.raytheon.com/	Provides radio frequency (RF) technology design, development and manufacturing	Mark E. Russell, VP Engineering, Technology & Mission Assurance 781.522.3000
National Instruments	National Instruments Corporation 11500 Mopac Expwy Austin, TX 78759-3504 http://www.ni.com/	5G wireless communications	Scott A Rust, Sr. VP Global Research and Development (512) 683-5680 scott.rust@ni.com http://www.ni.com/
Fraunhofer Institute of Reliability and Microintegration	Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM Gustav-Meyer-Allee 25 13355 Berlin http://www.izm.fraunhofer.de/en/feature_topics/5g-and-millimeter-wave-based-rf-systems.html	Innovative RF design of miniaturized mm-wave smart antenna systems and on RF- and photonic-system-integration using a combination of our holistic RF design approach[54]	Dr.-Ivan Ndip, Head of the RF & Smart Sencor Systems Department Phone +49 30 46403-679
Millimeter Wave Products, Inc.	Millimeter Wave Products, Inc. 2100 Tall Pines Dr Largo, FL 33771 http://www.miwv.com/	35+ years in design of microwave and millimeter-wave antennas, custom designs to telecommunication,	Mark Smith, President (727) 536-0033 mark@miwv.com

[54] Dr. Ivan Ndip, Frauhofer IZM, http://www.izm.fraunhofer.de/en/feature_topics/5g-and-millimeter-wave-based-rf-systems.html (accessed January 6,2017).

		industrial, military, testing, electronic warfare, research and development.	
Trimble	Trimble Inc., 935 Stewart Drive Sunnyvale, California 94085 http://www.trimble.com/	GPS, wireless communications, antenna. integrates its positioning expertise in GPS, laser, optical and inertial technologies with application software, wireless communications, and services to provide complete commercial solutions.	Ralph F. Eschenbach, VP Engineering (937) 233-8921 ralph_eschenbach@trimble.com
Micro-Ant LLC	4722 Wesconnett Blvd, Jacksonville, FL 32210 http://www.micro-ant.com/ 904-683-8394 Info@Micro-Ant.com	Antenna development and manufacturing	Greg Poe – CTO, Electrical Engineering 904-551-9317 – GPoe@Micro-Ant.com
Epiq Soutions	165 Commerce Dr. Suite #204 Schaumburg, IL 60173 http://www.epiqsolutions.com/ 847.598.0218	Small form factor software defined radio platforms for RF flexibility, performance and signal processing capacity.	Aaron Madsen, Chief Technology Officer 847-348-3689 aaron@epiqsolutions.com

We recommend developing a preliminary plan for deal-making before meeting with targets. This plan should be openly discussed with the target and a consensus one developed if they are interested in exploring being an investor/partner/licensee after meeting with the client.

Revenue Projection

Market and revenue projections are always an educated guess based on the relevant information available. Because markets are changing and technology is constantly advancing, it is not possible to make a definitive projection, yet it is possible to make a well-informed estimate.

For TNAs®, Foresight employs two widely used methods to estimate total addressable market and potential revenues: Bottom Up or Top Down. We then calculate a growth rate and market share. We try to estimate growth rate in light of the phase of the market. This is because market phase influences the slope for product sales, which directly affects the sales growth potential for the technology. Other points of consideration that are common across both approaches for revenue projections include the overall competitive advantage of this technology, how much education and awareness building will be required to allow buyers to

appreciate these advantages, and the potential for stakeholders and others to create pull-through by advocating this technology.

Unless clear market data is available, we typically estimate market share by beginning with the total addressable market in any given year. We then consider the current phase of the market (which influences what percentage of the total addressable market might be buying), barriers to entry (which eliminate potential customer segments), drivers (which skew buying forward or backward in time and affect what the buyer might seek in new technology), and the competitive landscape (which influences how the buyers might be divided up among competing offerings). Once we obtain a suitable estimate for the number of buyers and the number of units that each will purchase, we can easily calculate an estimate for the total number of units that can be sold. Multiplying this number by the unit price (as mentioned in the Price Table above) gives a revenue projection that was built from the bottom up. Dividing the revenues by the market size gives a potential market share, which should be taken as a sales goal or objective for this technology.

If we cannot get the data we need, we try to do a Threshold Analysis. In this approach, we see how many sales we feel might occur, based on expert and end-user feedback and other data. If that looks sufficient to justify moving forward with commercialization, we say the threshold is passed.

As our budget and time is limited, what is important is to see how we constructed the estimates and use this information to inform subsequent estimates. These estimates should not be taken as definitive. They are merely preliminary.

Potential investors/partners/licensees will want to know how much money they can make with this technology. Given the analysis to date, we can make a very preliminary projection of gross revenues the technology could generate using $5 as the price per unit.

1) Year One: $160,000 based on 32,000units sold
2) Year Two: $365,000 based on 73,000 units sold
3) Year Three: $930,000 based on 186,000 units sold
4) Year Four: $1,635,000 based on 327,000 units sold
5) Year Five: $2,645,000 based on 529,000 units sold

The analysis above is based on the chip antenna market growth of 13.1% between 2017 ($1.615 billion) and 2021 ($2.644 billion). By taking the total market gross revenues and each year's preliminary revenue estimate, we can derive a preliminary market share goal that begins at 0.01% and ends at 0.1% after five years from the date of market entry. The addition other market niches and applications or movement into high volume manufacturing such as for cell phones (which would reduce the per item price) change this forecast.

We also attempted to provide an estimate of an industry average royalty rate based on the analysis of the relevant deals that will assist in the valuation of your technology.

Examples of Relevant Deals		
Parties	***Key Terms***	***Date***
Acer Inc.	Cross license of patents related to data processing apparatus royalties set between 1 percent and 5 percent of the value of the finished product units made	March 1996
Apple Computer	Communication interface royalties of $1 per port from chip and system makers for units made	November 1995
Consortium of Computer Manufacturers	Communication interface royalties of 25 cents per product units made	November 1999
University of Connecticut	Semiconductor platform royalties of 3%	April 2003