

Review on Miniature & mm- wave Antennas for LoRa & 5G Wireless Communication

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Abstract: According to the drastic growth of Internet of Things (IoT) market, for a direct incorporation between the physical world and computer-based frameworks, IoT enables the devices to be detected and controlled remotely to enhance the efficiency. The terms IoT and 5G are used conversely because of the shared traits in the intents of both. Due to the rapid growth of IoT, Long Range (LoRa) technology become popular. In this paper, review of different shapes of miniature & mm-wave antenna for LoRa device & 5G wireless communication are presented. Recent advances in miniature & mm-wave antenna are reported and design guidelines are discussed. In particular, five different designs are identified from the recent literature based on their attractive characteristics that support 5G requirements and applications & LoRa Technology.

Index Terms: Internet of Things, Long Range Technology, Fifth Generation, Miniature Antenna, mm-wave Antenna.

I. INTRODUCTION

A decade before, humans have emerged drastically with the growth of industrial revolution. The 4th industrial revolution is the era where a new generation of wireless communication enables widespread

connectivity between machines and objects. The communication system needs to support more than twenty-five billion connected devices by year 2020. It is expected the 5th generation (5G) wireless mobile communication will allow to connect world of humans and objects. The major doubt arises how the 5G is going to meet the challenges by the year 2020[1]. The 5G is categorized into three generic services such as extreme Mobile Broad Band (xMBB), massive Machine-Type Communications (mMTC), and ultra-reliable Machine-Type Communication (uMTC) in Fig. 1 [2].

The xMBB provides extremely high data rates in the range of Gbps. The uMTC deals with ultra-reliable and time efficient devices. Another type of uMTC is reliable communication for manufacturing in factory. The mMTC enables 5G services to lots of devices with energy efficiency. Nowadays, the Antennas, sensors and the actuators are widely deployed for human-machine-centric communication.

A. Internet of Things

With the development of Internet of Things (IoT) technology, more and more practical applications of IoT technology can be found in many industries today. Widely installed short range radio connectivity (e.g. Bluetooth and ZigBee) are not suitable for the environment which require long-range performance with low bandwidth. Although M2M solution based on cellular technology can provide large coverage but it consumes a large amount of power. IoT provides a better solution to deal with such massive number of devices going under concurrent evolution of technology with underlying parameters like coverage, reliability, latency and cost effectiveness.

B. LoRa (Long Range) Technology

Low-Power, Wide-Area (LPWA) is the technology targeting at these emerging applications and markets at lower cost points and better power consumptions [4]. It is perfectly suitable for the IoT applications that only need to transmit tiny amounts of information in long range. Before 2013, the term 'LPWA' did not even exist. However, as the IoT market expand rapidly, LPWA has become one of the fast growing space in IoT. Many LPWA technologies has arisen in both licensed and unlicensed market such as LTE-M, SigFox, LoRa, Narrow Band (NB)-IoT and so on. Among these technologies, LoRa is the emerging technology with many advantages as shown in Fig.2 [5]. The LoRa communication operates in the unlicensed frequency band [6]:

- EUROPA 863-870MHz ISM Band: 3 channels,
Central frequencies: 868.10 MHz, 868.30 MHz, 868.50 MHz;
- EU 433MHz ISM Band: 3 channels,
Central frequencies: 433.175 MHz, 433.375 MHz, 433.575 MHz;
- US 902-928MHz ISM Band;
- China 779-787MHz ISM Band;
- China 470-510MHz Band;
- Australia 915-928MHz ISM Band;
- ISM Band 923-923.5MHz.

C. 5G Spectrum

The 5G networks are likely to operate in the centimetrewave (3–30 GHz) and millimetre-wave (30–300 GHz) frequency bands [7, 8]. 5G will demand a revolution, since they are going to be designed for short wavelengths (mm-waves), which easily fit in handsets, but are still long enough to bend around or penetrate obstacles, such as buildings and foliage. Additionally, mm-waves suffer from high attenuation due to rain. To overcome all these challenges, as well as free-space attenuation, different antenna types have been exploited for 5G networks. Most works published in literature on 5G antennas are concerning MIMO (multiple input multiple output) and beam steering antennas [9–14]. In recent years, many research efforts have been observed towards designing specific antennas for IoT applications with a narrow

bandwidth, such as a miniature antenna for IoT [15], a dual band antenna [16], or a compact reconfigurable antenna [17]. However, the selection of a specific antenna may be a real challenge. For a direct incorporation between the physical world and computer-based frameworks, IoT enables the devices to be detected and controlled remotely to enhance the efficiency. The terms IoT and 5G are used conversely because of the shared traits in the intents of both. LoRa, one of the lastborn and most promising technologies for the wide-area IoT. Some of research efforts are focused on identifying suitable antenna for fifth-generation communication and LoRa applications, especially to enable handling all devices by one system [18].

Therefore, in this paper, we compare and describe different antenna design for 5G wireless communication and LoRa technology.

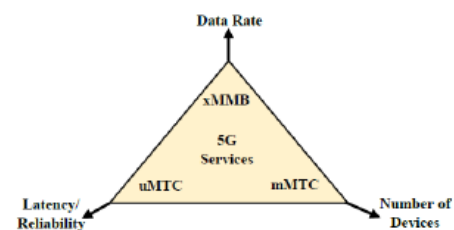


Fig. 1. The 5G generic Services [2]

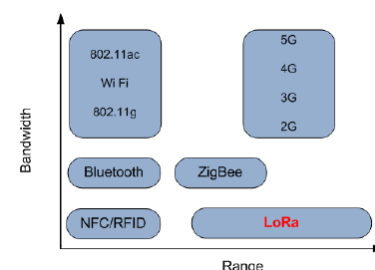


Fig. 2. Wireless communication protocols comparison [5].

II. LITERATURE SURVEY

A. Quad Band Antenna for LoRa

Quad-band Double-PIFA (Planar Inverted-F Antenna) combined with DGS (Defected Ground Structure) for Internet of Things (IoT) applications as shown in fig. 3(a) & (b) [19]. The antenna is compact in size with radiating patch of 184 mm^2 basing on RO4350B substrate with height of 1.52 mm. Operating at 900MHz, 1.8GHz, 2.6GHz and 5GHz with large bandwidth of 6.67%, 11.11%, 5.77% and 16%, respectively. This antenna is suitable for all typical IoT bands which include sub-GHz band of 908 MHz and 915 MHz; LTE-A band of No3 (1.8GHz) and No7 (2.6GHz) and 802.11n, ac of 5GHz.

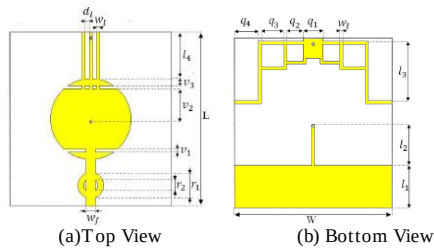


Fig. 3. Structure of D-PIFA [19]

B. Wide Band Antenna for IoT

The antenna consists of a stepped impedance feed line, a rectangular radiator and a ground plane. Here optimization of antenna is carried out in two case (i) the miniaturization-oriented optimization as shown in fig. 4(a) & (b) and (ii) the matching-oriented design as shown in fig. 5(a) & (b) [20]. This antenna is implemented on Taconic RF-35 substrate which has dimensions of only $3.7 \text{ mm} \times 11.8 \text{ mm}$ and a footprint of 44 mm^2 & 66 mm^2 , an omnidirectional radiation pattern, and an excellent pattern stability. The average in-band total efficiencies for both antennas are over 90% (92% for Antenna I and 96.5% for Antenna II). This antenna is suitable for prescribed frequency range of 5 GHz to 10 GHz.



Fig. 4. Antenna prototype for miniaturization oriented optimization [20]



Fig. 5. Antenna prototype for matching oriented optimization [20]

C. UIT & UCA Antenna for LoRa

The miniature antenna for LoRa device are presented here with dimension of $0.06\lambda \times 0.1\lambda$, they are printed on $34 \times 80 \times 0.8 \text{ mm}^3$ FR-4 board as shown in fig. 6[21]. This antennas operate at 868 MHz frequency band which is a sub-GHz frequency suitable for IoT. The radiation efficiency of both antennas UCA & UIT are 73% & 74%.

D. Ultra-Narrow Band Miniature Antennas for LoRa

Ultra Narrow band (UNB) miniature antenna is designed for IoT application as shown in Fig. 7 is constituted by a folded wire placed in front of a $0.5\lambda \times 0.5\lambda$ ground plane that is shorted close to the feed which has several advantages [22]. Secondly, the antenna

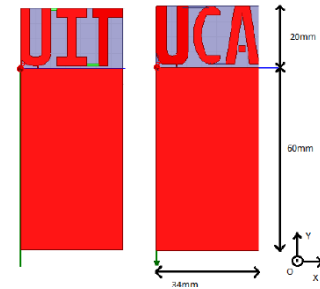


Fig. 6. UIT & UCA Antenna Designs [21]

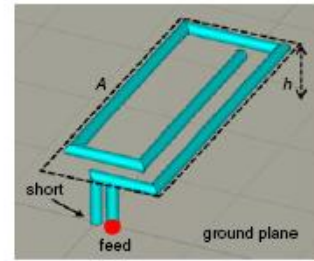


Fig. 7. Structure of UNB Antenna [22]

TABLE I
COMPARISON BETWEEN DIFFERENT ANTENNA DESIGN & PERFORMANCE FOR LoRa

Ref. No.	Dimension of Antenna (mm^2)	Substrate Used	Resonant frequency of IoT (MHz)	Radiation efficiency (%)	Antenna gain (dB)
Ref [19]	56x60x1.52	RO4350B	906	80.8	0.8
			915	80.8	0.8
			1800	99.9	2.28
			2600	96.2	3.77
			5000	93.6	2.9
Ref [20]	2.70x3.74x5.36	Taconic RF-35	5000	92	Not given
	5.43x3.91x6.05		10000	95	
Ref [21]	34x80x0.8	FR-4	868	73	0.71
Ref [22]	28x10x5	Copper (PEC)	868	63	Not given
Ref [23]	25x60x1	FR-4	915	Not given	Not given
			2450		
			3500		
			5800		

E. Waveguide-Based Antenna Arrays for 5G Networks

Two high-performance waveguide-based antenna arrays are designed for 5G cellular networks, operating at 28 GHz band with gain 12dBi and dual-band sectorial coverage using the 28 and 38 GHz bands with gain up to 15.6 dBi [24]. (i) Ring-based slotted waveguide antenna array (SWAA) is filled with Teflon—a low-loss polytetrafluoroethylene (PTFE) dielectric material shown as in fig. (8). They have milled the entire metallic structure, as the integration of the waveguide-based periodic metal collar and waveguide feeder, rather than alternating metal and dielectric rings. This ring based SWAA provides a bandwidth of approximately 7.7% from 26.85 to 29 GHz. The SWAA measured gain was 12.25 dBi for 28 GHz. Since the Ring-based SWAA has omnidirectional coverage in mm-wave applications, it is widely used in shopping malls, theatres, convention centers, and stadiums. (ii) Dual-Band slotted waveguide antenna array, is made of aluminum as shown in fig. (9). It has two slot groups milled on each waveguide broadside face, with the purpose of allowing simultaneous operation over 28 and 38GHz frequency bands. This SWAA provides two wide bandwidths: the first one of 26.36% from 24.7 to 32.2 GHz & the second one of 9.78% from 35.5 to 39.15 GHz. The dual-band SWAA provides a gain of 12.6 and 15.6 dBi for 28 and 38 GHz, respectively. This dual-band SWAA can be applied to adaptive 5G networks in two different ways as a function of the radio mobile environment and customer quality of service using two different bands independently.

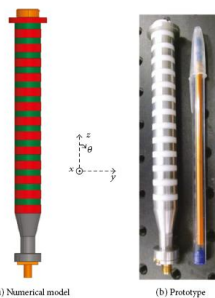


Fig. 8. Omnidirectional ring - based SWAA [24]

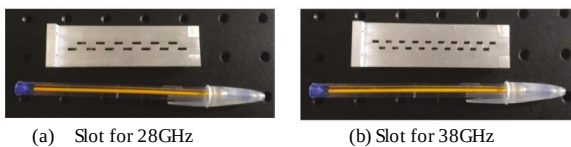


Fig. 9. Dual band slotted waveguide antenna array [24]

F. Flexible Microstrip Grid Array Antenna For 5G

A flexible microstrip grid array antenna (MGAA) is fabricated by printing the patch and the ground plane using a 0.25-mm-thick conductive rubber layer onto a 1.9 mm thick Polydimethylsiloxane (PDMS) substrate layer as shown in fig. 10[25]. The antenna was designed to operate at 14 GHz frequency band. It is composed of 24 radiating elements to achieve a high gain and compact size characteristics. The gain at 14 GHz is 8.7 dBi while the highest gain

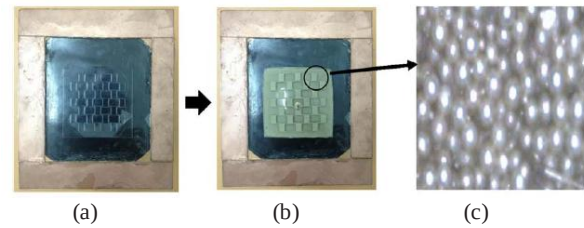


Fig. 10. Flexible microstrip grid array antenna [25]

(a) Conductive rubber mold was attached to cured PDMS surface, (b) liquid conductive rubber was poured into the mold, (c) cured conductive rubber image taken using dino-lite digital microscope.

for this antenna is 11.2 dBi at 15.5 GHz. This antenna is suitable for future flexible and conformal-5G mobile communication applications and wearable applications due to PDMS and conductive rubber with good return loss even at bending state.

G. 15 GHz Grid Array Antenna For 5G

A compact grid array antenna implemented using FR4 substrate for 5G Mobile Communications at 15 GHz as shown in fig. (11). The antenna has dimensions of 49 mm X 3.58 mm X 31.6 mm with 23 radiating elements to provide high gain [26]. It is excited using coaxial feeding technique. The antenna has achieved an impedance bandwidth of 2.1GHz from 13.8 GHz to 15.9 GHz with a gain of 14.4 dBi at 15.9 GHz. The maximum efficiency of the antenna is 66% at 15.9GHz. It is therefore good for mobile communications covering the 5G proposed band of 14.4–15.35 GHz.

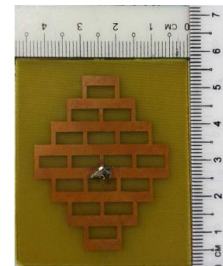


Fig. 11. Grid Array Antenna [26]

H. Compact Planar Inverted-F Antenna for 5G

The design is based on a compact planar inverted-F antenna (PIFA) with single layer dielectric load of a superstrate to enhance the gain and achieve a wide impedance bandwidth which has the advantage of high efficiency [27]. It covers the 28 GHz millimeter wave frequency bands with size of 15mm x 15mm. The antenna, is printed on a Rogers5870 substrate with a thickness of 0.635mm and copper-cladding thickness of 0.035mm as shown in fig. (12). The minimum & maximum total efficiencies are 88% and 96%, at 27.47 GHz and 28 GHz, respectively. The maximum and minimum realized gains are 8.8 dBi and 8.25 dBi, at 28 GHz and 28.5 GHz, respectively.

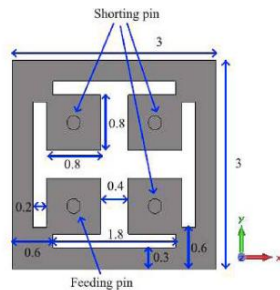


Fig. 12. Geometry of Compact planar inverted F- antenna [27]

I. T-Shaped Patch Antenna

The next design that operates in the mm-wave band is a T-Shaped patch antenna that was presented in [28] as shown in Fig. 13. The PET substrate was used as it offers some advantages; low cost, high flexibility, harm less to human body and resistive towards environmental effects. The T-shaped antenna has a length of 4.7mm and is printed on 16mm x 16mm PET substrate. Feeding is achieved using a coplanar waveguide and aperture in the ground plane. The peak gain of antenna is 8.2dBi at 38.75GHz and the gain is above 4dBi in the complete range of operation.

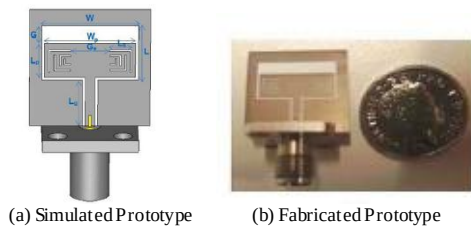


Fig. 13. Prototype of T-Shaped Antenna [28]

TABLE – II
COMPARISON OF DIFFERENT DESIGN OF mm-WAVE ANTENNA & ITS
PERFORMANCE FOR 5G

Ref. No.	Dimension of Antenna (mm)	Substrate Used	Resonant Frequency for 5G (GHz)	Radiation Efficiency (%)	Gain (dBi)
Ref. [24]	15x9.92x8	Teflon (PTFE)	28	Not given	12.25
	24.1x87.4 x1.77	Aluminium	28-38		12.6 – 15.6
Ref. [25]	60x60x2.4	Polydimethylsiloxane	14	Not given	8.7
			15.5		11.2
Ref. [26]	49x3.58x3.16	FR4	15.9	66	14.4
Ref. [27]	4x4x1.34	Rogers5870	27.47	88	8.8
			28	96	8.25
Ref. [28]	16x16x4.7	Polyethylene terephthalate (PET)	38.75	Not given	8.2

III. CHALLENGES

IoT & 5G together is opening up new ways to improve our lives and work. But the quest to create a truly connected world is giving rise to fresh challenges for those designing the antenna. Designers of IoT devices in 5G wireless communication using LoRa Technology (Wide area IoT) face many challenges when it comes to create small, lightweight, Low power consumption and low-cost devices that deliver high-quality RF performance. The antenna is a key part of the design, and product developers must consider size, RF efficiency, Power consumption and detuning issues when choosing the right kind of antenna to use. Making the right decision is particularly important when an antenna architecture design may be used in more than one type of housing.

IV. CONCLUSION

This survey paper is focused on different antenna designs & its performance which are well suited for LoRa & 5G Wireless communication. This has been identified based on their attractive characteristics that supports LoRa and 5G requirements & applications. Nevertheless, useful solution are still less and suffer from different problems like complexity of structure, reduction of gain, Low efficiency & high power consumption.

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