*International Journal on Emerging Technologies* **9**(2): 17-22(2018)

**ISSN No. (Print) : 0975-8364**
**ISSN No. (Online) : 2249-3255**

# A Review 5G using Millimeter Wave in Ultra-Reliable Machine-to-Machine Communications

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*(Received 05 June, 2017 Accepted 15 July, 2018)*
*(Published by Research Trend, Website: www.researchtrend.net)*

**ABSTRACT: Focus on fifth generation (5G) mobile communication for ultra-reliable low-latency communications. With the expected superior performance to the current generation of mobile networks, 5G systems are poised to support new and diverse usage scenarios and applications, thus enriching the lives of citizens and the productivity of industry and public sectors. The widely accepted scenarios for 5G include enhanced mobile broadband (eMBB), addressing human-centric use cases for access to multimedia content, services and data; ultra-reliable low-latency communications (URLLC) with strict requirements, especially in terms of latency and reliability; and massive machine type communications (mMTC) for a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. The articles in this section present the most relevant scenarios, prominent research outcomes, and state-of-the-art advances of 5G systems for URLLC achieving the Third Generation Partnership Project (3GPP) targets on latency and reliability requirements to successfully deliver delay-sensitive information.**

**Keywords.** fifth generation, multimedia, machine type communications.

## I. INTRODUCTION

Performance to the current generation of mobile networks, fifth generation (5G) systems are poised to support new and diverse usage scenarios and applications, thus enriching the lives of citizens and the productivity of industry and public sectors. The widely accepted scenarios for 5G include enhanced mobile broadband (eMBB), addressing human-centric use cases for access to multimedia content, services and data; ultra-reliable low-latency communications (URLLC) with strict requirements, especially in terms of latency and reliability; and massive machine type communications (mMTC) for a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. This Special Issue (SI) of *IEEE Network* aims at presenting the most relevant scenarios, prominent research outcomes, and state-of-the-art advances of 5G systems for URLLC achieving the Third Generation Partnership Project (3GPP) targets on latency and reliability requirements to successfully deliver delay-sensitive information. In 3GPP, the performance target for control plane latency is 10 ms, and for user plane latency it is 0.5 ms for downlink and uplink directions, separately. The mobility interruption time (MIT) must be 0 ms for both intra-frequency and inter-frequency handovers for intra-New Radio (NR) mobility. Reliability, defined as success probability of transmitting a predefined number of bytes within a certain delay, depends on the usage scenario. For instance, the target reliability for the “general URLLC case” is 99.999 percent (five nines) with user plane latency of 1 ms and payload size of 32 bytes. This SI brings together key contributions of researchers from industry and academia, which address the above challenges and sheds light on some fundamental technical aspects of 5G architectures, building blocks, and key enabling technologies for URLLC, such as ultra-low-latency air interfaces, robust waveforms, and wireless relaying; optimized high-performance unlicensed/shared spectrum solutions; dynamic network slicing, flexible virtual network functions placement at the edge, and continuous self-optimization and cognition; and packet duplication, handover, and multidimensional multi-connectivity mechanisms optimized for ultra-reliability and minimal service interruption time.

In response to the Call for Papers, a large number of manuscripts were received. The submissions underwent a rigorous review process, new ideas and endeavors within the global research and innovation community.

In addition to providing readers with relevant background information and feasible solutions to the main technical design challenges of future 5G systems for to enable gigabit wireless access with reliable communication, a number of candidate solutions are currently investigated for 5G: 1) higher frequency spectrum, e.g., millimeter wave (mmWave); 2) advanced spectral-efficient techniques, e.g., massive multiple-input multiple-output (MIMO); and 3) ultra dense small cells [1]. This work explores the above techniques to enhance the wireless access [1]–[3]. Massive MIMO yields remarkable properties such as high signal-to-interference-plusnoise ratio due to large antenna gains, and extreme spatial multiplexing gain [3], [4]. Specially, mm Wave frequency bands offer huge bandwidth [5], while it allows for packing massive antennas for highly directional beam forming [5]. A unique peculiarity of mmWave is that mmWave links are very sensitive to blockage, which gives rise to unstable connectivity and unreliable communication [5]. To overcome such challenge, we leverage principles of risk-sensitive reinforcement learning (RSL) and exploit the multiple antennas diversity and higher bandwidth to optimize transmission to achieve gigabit data rates, while considering the sensitivity of mmWave links to provide ultra-reliable communication (URC). The prime motivation behind using RSL stems from the fact that the risk-sensitive utility function to be optimized is a function of not only the average but also the variance [6], and thus it captures the tail of rate distribution to enable URC. While our proposed algorithm is fully distributed, which does not require full network observation, and thus the cost of channel estimation and signaling synchronization is reduced. Via numerical experiments, we showcase the inherently key tradeoffs between (*i*) reliability/data rates and network density,

and (*ii*) availability and network density. In authors provided the principles of ultra-reliable and low latency communication (URLLC) and described some techniques to support URLLC. Recently, the problem of low latency communication [5] and URLLC [7] for 5G mm Wave network was studied to evaluate the performance under the impact of traffic dispersion and network densification. Moreover, a reinforcement learning (RL) approach to power control and rate adaptation was studied in [8]. All these works focus on maximizing the time average of network throughput or minimizing the mean delay without providing any guarantees for higher order moments (e.g., variance, skewness, kurtosis, we depart from the classical average based system design and instead take account of higher order moments in the utility function to formulate a RSL framework through which every small cell optimizes its transmission while taking into account signal fluctuations. As an intrinsic part of the Internet of Things (IoT) ecosystem, machine-to-machine (M2M) communications are expected to provide ubiquitous connectivity between machines. Millimeter-wave (mmWave) communication is another promising technology for the future communication systems to alleviate the pressure of scarce spectrum resources. For this reason, in this paper, we consider multi-hop M2M communications, where a machine-type communication (MTC) device with the limited transmit power relays to help other devices using mm Wave. To be specific, we focus on hop distance statistics and their impacts on system performances in multi-hop wireless networks (MWNs) with directional antenna arrays in mm Wave for M2M communications. Different from microwave systems, in mm Wave communications, wireless channel suffers from blockage by obstacles that heavily attenuate line-of-sight signals, which may result in limited per-hop progress in MWNs. We consider two routing strategies aiming at different types of applications and derive the probability distributions of their hop distances. Moreover, we provide their baseline statistics assuming the blockage-free scenario to quantify the impact of blockages. Based on the hop distance analysis, we propose a method to estimate the end-to-end performances (e.g., outage probability, hop count, and transmit energy) of the mm Wave MWNs, which provides important insights into mm Wave MWN design without time-consuming and repetitive end-to-end simulation.

With the advent of the Internet of Things (IoT), which shifts the paradigm of the Internet from human interconnection into a network of devices, it is predicted that almost 50 billion devices will be connected by 2020 [1]. As a key technology to realize the IoT ecosystem, machine-to-machine (M2M) communication enables wireless devices to constantly interact with each other as well as with their environments without direct human intervention Furthermore, to enhance network capacity, a fifth generation (5G) cellular system is envisioned to have significantly greater spectrum allocations at millimeter-wave (mmWave) frequency bands. For this reason, in this paper, we investigate multi-hop wireless networks for M2M communications using mmWave.

M2M communication is desirable to interact with a large number of remote devices acting as the interface with end customers, utilities, etc. [5]. For example, various machine-type communication (MTC) devices such as smart meters, signboards, cameras, remote sensors, laptops, and appliances can be interconnected to support wide range of applications. Considering the limited capability of energy harvesting technologies as noted in [9], the subsequent wireless communication techniques must be short-range with low data rates, which makes multi-hop ad hoc networking absolutely necessary in realistic deployment of a large volume of MTC devices [8]. In this paper, we consider M2M communications with low-cost devices such as sensors and low-power mobile machines for applications such as healthcare, energy management, and entertainment [5]. As a related topic, device-to-device (D2D) communication is an emerging technology in cellular networks, where the devices in proximity can directly communicate with each other. From an architectural viewpoint, D2D communication may look similar to multi-hop M2M communication such as mobile ad hoc networks [3].

However, D2D communication is mainly for single hop communications with the involvement of the cellular network in the control plane, and it generally does not inherit multi-hop routing issue in multi-hop wireless networks (MWNs) We note that such types of D2D communication (single or small number of hops) are out of the scope of this paper. Instead, in this work, we consider multi-hop M2M communications using mm Wave.

A fundamental question in MWNs is whether it is advantageous to route over many short hops (short-hop routing) or over a smaller number of longer hops (long-hop routing), as highlighted In general, the long-hop routing is preferred for delay-sensitive applications, while the short-hop routing is desirable to reduce transmit power consumption For this reason, the hop distance statistics of different routing strategies are extensively studied in microwave systems. For example, in the hop distance statistics are used to derive the transmit energy consumption assuming Rayleigh fading channel. As in the microwave systems, the routing strategy associated with the hop distance characteristics is crucial in the future generation ad hoc networks using mmWave because the M2M networks with battery-powered devices inherently entail the limited transmission range, which requires multi-hop transmit.

To cope with dramatic increase in mobile traffic and extreme device density, the future fifth generation (5G) cellular networks are expected to have mmWave carrier frequency with massive bandwidths and unprecedented number of antennas Enabled by the availability of a wide spectrum and recent advances in radio frequency integrated circuit (RFIC) technologies, mmWave communication is a key technology to support ever-increasing capacity demand At mmWave frequency, highly directional transmission using antenna arrays is an effective technique to overcome its heavier path-loss compared to the microwave systems However, mmWave signals exhibit reduced diffraction and higher susceptibility to blockage compared to microwave signals; thus, mmWave channel is nearly bimodal depending on the presence or absence of line-of-sight (LoS) For this reason, if the LoS path is blocked by obstacles, an outage event may occur for high data rate applications such as multimedia data transfer that cannot be supported solely by non-LoS paths.

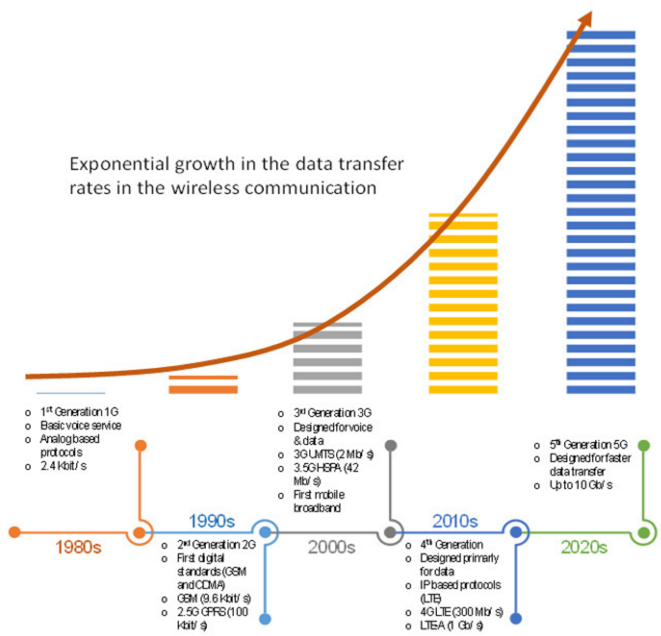
In the authors propose a stochastic model of such blockage effects in mmWave channels, where the probability of the existence of the LoS path is an exponentially decaying function of the distance between two nodes. Using this model, the authors in study the coverage and rate performance in mmWave cellular networks. Moreover, in the signal-to-interference-and-noise-ratio in the mmWave ad hoc network is analyzed in terms of a information theoretical metric (transmission capacity). In this paper, we also assume the blockage model in and focus on the hop distance statistics under the blockage effects. We provide insights to better design multi-hop mmWave M2M communication systems using two representative and generic routing strategies with maximum and minimum possible hop distances, which can be exploited to build routing schemes and higher-layer protocols in the future. The main contributions of this paper are threefold: first, we derive closed form expressions of probability distributions of hop distances for two different routing schemes in the mmWave MWNs unlike the microwave MWNs in second, we derive the blockage-free hop distance statistics as a baseline to quantify the impact of the blockage effect; third, using the derived hop distance statistics, we estimate end-to-end performances such as outage probability, hop count, and transmit energy, which are compared with simulation results to validate our analysis.

The rest of this paper is organized as follows. The system model is introduced in, per-hop outage probability and the distance distribution of line-of-sight (LoS) links are derived in the presence of blockage effects. we introduce two routing strategies targeting different system requirements and analyze their hop distance statistics. In we propose a method to estimate the end-to-end system performances (e.g., outage probability, hop count, and transmit energy) of mmWave MWNs based on the per-hop statistics. The blockage-free performances are analyzed as baseline cases to quantify the impact of the blockage effects in Numerical results are presented in to validate our analysis with simulation results. Conclusions are provided in

## II. SYSTEM MODEL

Stochastic geometry is a powerful tool to model and analyze wireless networks assuming that the locations of nodes or the network structure are random in nature because of their unpredictable spatial characteristics Poisson point process (PPP), where the number of points (nodes) inside any compact set is a Poisson random variable and the points are uniformly distributed in the compact set, is the most widely used spatial model for networks with uniform node density such as ad hoc networks and cellular networks For this reason, we also assume PPP for the spatial distribution of MTC devices. To be specific, we consider a multi-hop M2M network using mm-wave as where nodes (devices), which are indicated by the black dots, are uniformly scattered according to a two-dimensional of intensity. In the age of digitalization, high-speed communication is on higher priority for all (consumers and enterprises). What if the wireless carriers impose caps on the rapidly growing data traffic and raise prices? What if we run out of airwaves for our striking increase in wireless data usage on our gadgets? So, how are these basic realities – high-speed communication needs, bandwidth shortage, and exploding data on several devices are addressed. All the electronic devices in our home use specific radio frequency spectrum which are typically restricted to frequencies of up to 30 GHz. This range is currently highly congested, hence modern wireless communication standards are focusing more on standards over 30 GHz (millimeter waves).

However, carriers can only squeeze a specific amount of data in a particular radio spectrum. As the number of wireless connected devices have been increasing in multifold, the efficiency in carrying the data has been dropping considerably owing to the network congestion. To overcome with the increasing amount of data, companies and governments are exploring alternative ways and formulating various strategies. Some of the solutions being considered are efficient management of spectrum usage (exploring the access to unused frequencies that have been reserved for TV stations, federal agencies), usage of alternative technologies to cover short-range communications, such as Wi-Fi, LTE-U, wider-area broadband access, cognitive radios, and also exploring other unused spectrum, for example, millimeter wave spectrum. This article focuses on the overview of technological advances, applications, and outlook of millimeter wave technology. The bandwidth shortage facing wireless carriers worldwide due to the rapid increase of mobile data growth and high-speed communication needs has driven the exploration of the millimeter wave frequency spectrum (30 GHz–300 GHz) that lies between the microwaves and the infrared waves. The advancement in technologies over the past decade has enabled the widespread use of millimeter wave to address the challenges of lower frequency and high-speed communications. The evolution of communication technologies from 1G to 5G has taken almost five decades from 1G in 1980s to 5G in 2020s. The possibility of achieving data rates of up to 10 Gbit/s (gigabit per second), where the data rates are restricted to less than 1 Gbit/s in microwave frequencies, has increased the application of millimeter waves to automotive radar solutions, high-speed point-to-point communication (WLANS and broadband access), streaming high-resolution videos, carry large amount of data, mobile and wireless networks.




Now, a number of manufacturers are producing components that can handle millimeter waves and semiconductor technologies are capable of operating at frequencies up to 90 GHz, especially in V-band (57 to 66 GHz) and E-band (71 to 86 GHz) applications. The 60 GHz (V-band from 57 to 64 GHz) unlicensed industrial-scientific-medical (ISM) band is getting lots of attention, especially for short-range wireless technologies, including IEEE 802.11ad WiGig (wireless Gigabit) Technology and Wireless HD. The WiGig technology, based on the 60 GHz spectrum, enables devices to communicate for a short range (distance of about 10 meters) at high data rates of up to 8Gbit/S. Some of the typical applications of Wireless HD include transmitting video from a tablet, laptop, set-top-box, to an HDTV, from a game or DVD player to a TV set; wireless video cameras; and wireless HD projectors.

With the growing demand for millimeter components, manufacturers are now developing technologies and affordable components with new semiconductor materials, such as gallium nitride (GaN), gallium arsenide (GaAs), silicon germanium (SiGe), and indium phosphide (InP). These components are also manufactured at very smaller sizes of about 40nm to make these components applicable in a wide range of applications. With the growing applications, millimeter-wave circuits are being packed into ICs. Companies, such as Infineon, Freescale Semiconductor (Acquired by NXP Semiconductors in 2015), and NXP Semiconductors, have developed Radar transceiver chipsets for automotive and industrial radar applications.Current mobile users require high-speed data transfer rates and more reliable services and the next generation (5G) wireless networks has the potential to deliver the required speed.

5G networks are expected to be driven by the increased wireless capacity and speeds offered by high-frequency millimeter waves. Today's wireless networks are handling more traffic with more people and devices consuming more data than ever before. However, all the traffic is overcrowded on the same bands of the radio-frequency spectrum. Researchers have been taking place in several universities across the globe and some cellular providers and other industry players have begun to test and use them to send data between two base stations. With several advantages of millimeter waves, such as large bandwidth (for higher data transfer rates), higher resolution, low interference (systems with a high immunity to cramming), small component sizes (for example, smaller antenna dimensions), increased security, and cost-efficacy, these are finding use in several commercial applications. Currently, millimeter waves are used majorly by only operators of satellites and radar systems and the usage has been expanding to medicine, astronomy, meteorology, and communications. The applications include automotive radars, healthcare, human body scanners, wireless data communication in virtual reality headsets, telecommunication, military & defense, industrial, satellite communication, imaging, nondestructive evaluation (NDE) applications. Millimeter waves open up more spectrum and reduces the congestion on the current radio spectrum. Today, a few electronic components were able to operate in millimeter waves, hence the millimeter wave's spectrum remained unused. However, this spectrum faces several challenges and acts as an obstacle for several players across industries. The major challenge has been the travelling media due to the poor penetration attributed to atmospheric and free-space path loss. Some of the challenges faced by millimeter waves include atmospheric absorption, free space loss, scattering of signal due to rain, mechanical resonance as these signal coincide with gaseous molecules (absorption increases at 24 and 60 GHz), degradation of system performance by brightness temperature, and non-line of sight issues (millimeter waves are blocked by physical objects such as trees and buildings, leading to signal loss and a reduced range), and costly components (Higher costs in manufacturing the small sized components with greater precision).

**What is going on**

-In August 2016, a group of students from New York University found that the millimeter waves could travel more than 10 kilometers in rural town of Riner in southwest Virginia. They detected millimeter waves at 14 spots that were within line of sight of the transmitter, where their receiver was shielded behind a hill or leafy grove. They achieved all this while broadcasting at 73 GHz with minimal power (less than 1 watt).

-In September 2016, Denso and Toyota have acquired the majority stake of Fujitsu TEN, a Japanese maker of infotainment and automotive electronics equipment and one of the world's leading developers of millimeter wave radar. As per the deal, Toyota Motor holds 35% and Denso will own 51% from the first quarter of 2017.

-In October 2016, Qualcomm announced the commercial availability of its first integrated 5G modem (Snapdragon X50 5G modem), which is capable of peak download speeds of 5 Gbit/s.

-In October 2016, Fujitsu Laboratories Ltd. (Japan) announced the development of a CMOS-based millimeter-wave signal generator that is capable of modulating its frequencies across a wide band of 76-81 GHz at faster speeds of ~ 200km/h. This development is focused on highly precise monitoring technology that works with ADAS (advanced driver assistance systems) systems that prevent detection errors, and with targets moving at different speeds, such as pedestrians or bicycles, using automotive radar.

-In November 2016, Facebook's Connectivity Lab, a team working to develop a variety of terrestrial and airborne technologies to help connect the world has tested a terrestrial point-to-point link in Southern California. Using a set of custom-built components with only 105 watts of total direct current (DC) power consumption at the transmitter and receiver recorded, the team achieved data rate of nearly 20 Gbit/s over 13 km with MMW technology.

-In February 2017, AT&T (US) acquired FiberTower Corporation (US) and its millimeter wave spectrum assets as part of its 5G network strategy. FiberTower owns licenses in the 24 GHz and 39 GHz bands and helps AT&T to strengthen its wireless services to carriers, enterprises and government entities.

-In February 2017, NEC Corporation (Japan) along with U.K. operators, BT group and EE Limited (Now a part of BT Group) agreed to work with the University of Salford to test the performance of vital millimeter wave mobile backhaul technology for 4G and 5G networks. The University of Salford acts as a research partner to undertake the most thorough testing.

-In May 2017, Texas Instruments (US) unveiled its new millimeter wave single-chip complementary metal-oxide semiconductor (CMOS) portfolio that include five solutions across two families of 76- to 81-GHz sensors with a complete end-to-end development platform. These are focused bringing an unprecedented degree of precision and intelligence to a range of applications, such as automotive, factory and building automation, and medical markets.

-In May 2017, Apple, Inc. (US) signed an application for an experimental license to test out new millimeter wave (5G) wireless technology that could significantly increase the speed and bandwidth of a cellular connection. As per the application, Apple seeks to assess cellular link performance in direct path and multipath environments between base station transmitters and receivers using he 5G spectrum.

-In June 2017, Hiroshima University and Mie Fujitsu Semiconductor Limited (MIFS) announced the development of a low-power millimeter-wave amplifier that that was fabricated using MIFS's Deeply Depleted Channel (DDC) technology. This amplifier feeds on 0.5 V power supply and covers the frequency range from 80 GHz to 106 GHz and makes future vehicles much safer.

## III. CONCLUSIONS

We studied the problem of providing multigigabit wireless access with reliable communication by optimizing the transmit beam and considering the link sensitivity in 5G mmWave networks. A distributed risk-sensitive RL based approach was proposed taking into account both mean and variance values of the mmWave links. Numerical results show that our proposed approach provides better services for all users. For instance, our proposed approach achieves a Pr(UT$\geq$ 10Gbps) is higher than 85%, whereas the baselines obtain less than 75% and 65% with 24 small cells.

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