AN ARCHITECTURE FOR M2M COMMUNICATIONS OVER CELLULAR NETWORKS USING CLUSTERING AND HYBRID TDMA-NOMA

By

Anthonya Barsha Rozario
Student ID. 16161003

A thesis submitted to the Department of Electrical and Electronic Engineering in partial
fulfillment of the requirements for the degree of
Master of Science in Electrical & Electronic Engineering

Department of Electrical and Electronic Engineering
Brac University
June 2019

Declaration

It is hereby declared that

1. The thesis submitted is my own original work while completing degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

Student's Full Name & Signature:

Anthonya Barsha Rozario
ID: 16161003

Approval Certificate

The Thesis titled “An Architecture for M2M Communications over Cellular Networks Using Clustering and Hybrid TDMA-NOMA”, submitted by Anthonya Barsha Rozario, ID:16161003, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Masters of Science in Electrical and Electronic Engineering** on 30 June**,** 2019.

BOARD OF EXAMINERS

1. Chairman

Dr. Md. Farhad Hossain
Professor
Department of Electrical and Electronic Engineering
BUET, Dhaka-1205, Bangladesh

2. Member (Ex-officio)

Dr. Shahidul Islam Khan
Professor and Chairperson
Department of Electrical and Electronic Engineering
BRAC University, Dhaka-1212, Bangladesh

3. Member

Dr. Saifur Rahman Sabuj
Assistant Professor
Department of Electrical and Electronic Engineering
BRAC University, Dhaka-1212, Bangladesh

4. Member (External)

Dr. A K M Nazrul Islam
Professor and Head
Head, Department of Electrical, Electronic and Communication Engineering (EECE)
MIST, Dhaka-1216, Bangladesh

Ethics Statement

This is to certify that this thesis titled "An Architecture for M2M Communications over Cellular Networks Using Clustering and Hybrid TDMA-NOMA", is the result of my study for partial fulfillment of Master of Science in EEE degree under supervision of Dr. Md. Farhad Hossain, Professor, Department of EEE, BUET and no part of this work has been submitted elsewhere partially or fully for the award of any other degree or diploma.A part of this thesis has been published as a conference paper in ICoICT 2018, Bandung, Indonesia. Any material reproduced in this project has been properly acknowledged.

Acknowledgements

I would like to express my greatest gratitude to the people who helped and supported me throughout this thesis. First, I would like to express our heartiest gratefulness to Almighty for his heavenly blessings. Without his blessings it would not possible to complete my thesis successfully.

Foremost, I would like to thank my respected supervisor, Dr. Md. Farhad Hossain, Professor, Department of EEE, Faculty of Engineering, BUET for giving me enormous support, advices and valued guidance concerning this thesis. It is his wise knowledge, motivation and patience, which made it possible to complete my thesis.

I would like to appreciate Dr. Shahidul Islam Khan, Chairman, BRAC University-Bangladesh, for his exceptional inspiration, vital encouragement and support.

Finally, I would like to thank my family and friends whose unconditional love, inspiration and valuable support has helped me to endure the hard work and complete this thesis.

Anthonya Barsha Rozario
ID: 16161003

Dedication

This thesis is dedicated to my beloved parents and sister.

Contents

List of Figures

List of Tables

List of Acronyms

BS	Base Station
CH	Cluster Head
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
M2M	Machine to Machine
NOMA	Non-Orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access
QoS	Quality of Service
RMa	Rural Macro Cell
SIC	Successive Interference Cancellation
TDMA	Time Division Multiple Access
UE	User Equipment
UMi	Urban Micro Cell
UMa	Urban Macro Cell
3GPP	Third Generation Partnership Project

List of Symbols

h	Average building height
C^m	Channel capacity of machines
M_i^X	Cluster Head Machine of cluster X
f_c	Carrier frequency
P_N	Noise power
h_{UT}	Receiver height of user terminal
σ	Shadow fading
W	Street width
T_c	Total transmission time
T^{mc}	Timeslots in machine to CH link
T^{mb}	Timeslots in machine to BS link
T^{cm}	Timeslots in CH to machine link
T^{cb}	Timeslots in CH to BS link
P_t^m	Transmit Power

Abstract

Machine-to-Machine (M2M) communications is regarded as one of the most essential technologies in the future communications system because of enabling enormous wireless machines to communicate without human interference. M2M communications is increasingly growing its popularity in present and future cellular networks for providing huge variety of available connectivity solutions, various ubiquitous services and global coverage. The demand of low energy consumption and high throughput applications, and the emergence of M2M communications has already drawn notable attention of many academia and industries. However, M2M communications will be experiencing multifarious challenges and complexities in the future standardization of 5G cellular networks. Therefore, robustness in M2M architecture is absolutely essential to manage numerous amount of machines and to cope up with their access loads effectively and efficiently. In light of this, this research thesis proposes a novel architecture for M2M communications over 5G cellular networks. *k*-means dynamic clustering for machines as well as energy based cluster head (CH) reselection method is applied in order to balance the power consumption within the machines to increase their battery life. For communication between CH and member machines, time division multiple access (TDMA) is proposed. On the other hand, for communication between CH and BS, non-orthogonal multiple access (NOMA) technology based power coding and successive interference cancellation (SIC) is implemented.

Performance of the proposed architecture is evaluated through extensive simulations for evaluating the system performance considering perfect communication and the newly developed 3D 5G wireless channel models. Impact of system parameters including number of machines, cell radius, transmit power and channel models on system performance are examined. Extensive simulations are carried out for evaluating the system performance considering the newly developed 3D 5G wireless channel models in terms of energy efficiency, life-time of machines and throughput. Our proposed M2M communication architecture identifies that with CH reselection and clustering technique, the number of transmission cycle, throughput and energy efficiency can be increased significantly. The proposed TDMA-NOMA based hybrid multiple access technique has substantially decreased the communication delay than the TDMA-TDMA based system. In addition, proposed M2M communication architecture will be extended for multi-cell cellular network considering inter-cell interference.

Chapter 1

Introduction

This chapter describes the background and the motivation for this research work done by briefly introducing the field and explaining the principle research problem. The objectives of this thesis are also presented in brief.

1.1 Machine to Machine Communications

Today's world is witnessing an exponential increase in the use of internet based smart devices. The introduction of Internet of Things (IoT) has brought coordination of multiple machines, devices and appliances connected to the internet through various communication networks. In next few years, billions of machines will consolidate with the IoT, driving minimization in human exertion and improvement in each division of day to day life [1]. Machine to machine (M2M) communications infrastructure is evolving to support this rapid growth of the IoT [2]. The widespread coverage of cellular networks and internet together offers the most promising foundation for the implementation of M2M communication and IoT [3].

M2M communications framework is a wide-ranging network with manifold applications and a massive number of interconnected heterogeneous machines (e.g., autonomous sensors, actuators, various smart appliances) as shown in Fig 1.1 [4]. In M2M, data communication occurs between a machine and a server, or directly between two machines. Different from conventional human to human communications, machines in M2M systems communicate with themselves without or with very less human intervention. Several key features of M2M are such as massive deployment of energy efficient and delay controlled operating devices with low mobility, emerging applications with diverse traffic characteristics, small packet transmission in the uplink and group based addressing [5], [6]. The ultimate objective of M2M communications is to construct ubiquitous connection among all the machines distributed over an extensive coverage area. In addition to this, M2M offer applications, such as e-health, smart grid, vehicular telematics, manufacturing, intelligent transportation are characterized by small-sized data information periodically or non-periodically transmitted by enormous M2M gadgets [7]. Moreover, by providing convenience insecurity, tracking, tracing, remote maintenance and facility management purpose, M2M has become one of the most compelling requirements of the future communications systems.

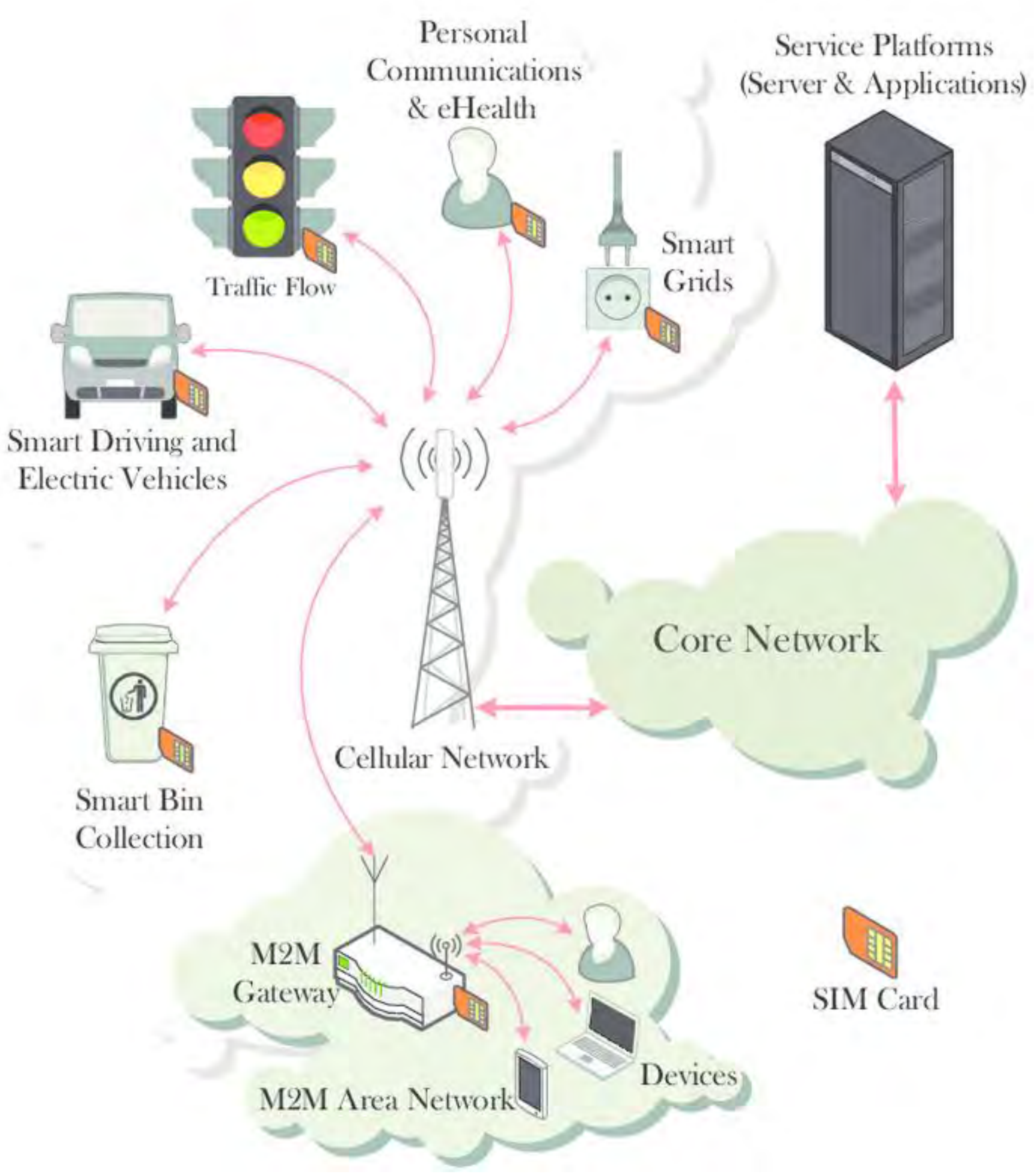

Fig. 1.1: M2M system architecture [8].

However, according to Cisco IBSG's prediction, there will be 50 billion machines connected to the Internet by 2020 [9] as shown in Fig 1.2. In IoT, a massive number of M2M devices (billions of sensors) will need access to the network periodically to transmit their payloads with very low data rates requirements. These devices include wireless sensor, weather change and environment sensors, and vehicular communication [10]. This throws a major challenge for future cellular network that how to manage the massive M2M traffic of connected devices and machines that require wireless connectivity. Moreover, energy management of billions of machines in the M2M system simultaneously is a massive task as there remains chances of data request collision as numerous machines attempt to establish connection with the base station (BS). The network architecture therefore, needs to be flexible enough to provide several key requirements like-overhead signaling congestion control, energy efficient transmission, flexible channel capacity, adequate Quality-of-Service (QoS) etc. Some challenges of M2M communication in future cellular network are discussed below.

- **Excessive Signaling Overhead:** One of the biggest issues in handling the M2M traffic is massive increase of signaling overhead due numerous of machines under a mobile cell area. When this huge M2M devices access the network, excessive access request to BS creates congestion resulting overhead signaling storm [11]. Thus, the whole cellular network becomes unable to serve and shows degraded performance.

- **Resource Allocation Difficulties**: M2M communications will face the challenge of satisfying diverse QoS requirements of the fast growing machines [12]. Under the same network, allocating radio resources for the huge M2M traffic will be a challenging task as they generate high signaling interference while transmission.

- **Security and Privacy Risks:** Today's enormous increase in IoT and M2M devices connected to the internet will introduce risk in security aspects as well. As M2M devices are pervasive communication devices, large amount of personal data's are collected from these machine which may belong to business, health care and other confidential applications [13]. Thus, M2M networks will require more secured filtering procedures, restricted firewalls and prevention procedures.

- **High Power Consumption and Cost**: In M2M communications, power consumption and cost are eminent design factors to make cellular networks feasible [14]. As M2M devices are remotely situated, low-power design is always a desire to save battery life of the device. However, power reduction in future cellular network may face difficulty asit is related to the system reliability, data transmission time, machine on mode time and various other things. Additionally, by reducing complexity of the machines, low cost design will be another crucial task to provide maximum coverage.

- **Usability and Design Variety:** Depending on different use case scenarios and requirements, providing software-driven customized network services is a challenging task for future networks. For instance, based on global market M2M architecture will face variety of design and concern aspects in different application platform. M2M market will witness new technologies, novel use cases and innovative business models in next upcoming years [15].

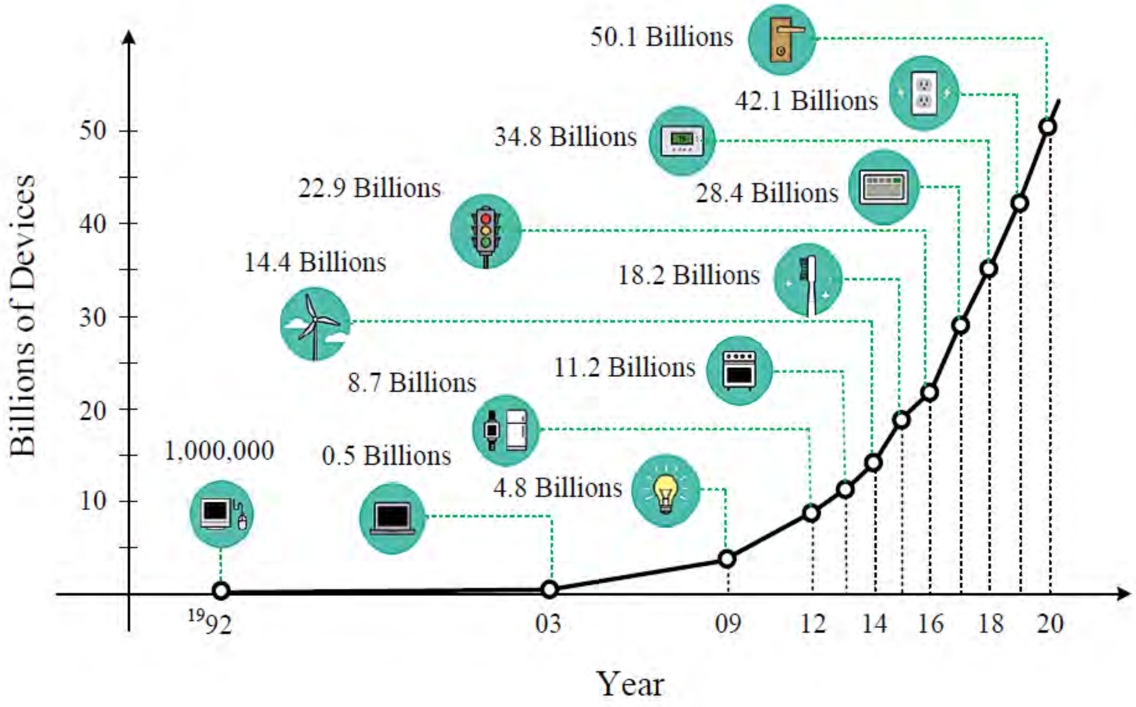

Fig.1.2: Expected number of connected devices to the internet [9].

For the next generation 5G cellular network, first and foremost concern will be supporting massive number of wireless machines interconnected by IoT under M2M link [16]. This future cellular networks will have to improve M2M communications with high throughput, reduced communication delay and signaling overhead, wide coverage, as well as increased battery lifetime. Therefore, several standardizations bodies such as the Third Generation Partnership Project (3GPP), European Telecommunications Standards Institute (ETSI), and Institute of Electrical and Electronics Engineers (IEEE) are working to develop technologies for this new generation of M2M/IoT communications [17]. In light of this, upcoming 5G networks are expected to arrange efficient support for the larger and diverse set of machines in all types of communication with programmable system protocols according to user requirements. Unlike the previous generation of networks, where control and processing tasks are heavily assigned to the infrastructure side; 5G aims to balance this factor by employing architectural changes from cell-centric to machine-centric design [18]. Native ubiquitous connectivity for massive M2M communications and IoT as well as enhancement in spectral efficiency, energy efficient network planning resource allocation and new spectrum sharing policy extend the potential of 5G for M2M [19].

1.2 Non-orthogonal Multiple Access (NOMA)

The explosive traffic growth in mobile communications has motivated research activities to design the next generation (5G) of mobile communication networks that can offer significant improvement in coverage, spectral efficiency and user experience [20]. Non-Orthogonal Multiple Access (NOMA) is a promising multiple access technique for 5G wireless communication networks due to its higher spectral efficiency and user fairness [21]. Compared to orthogonal frequency division multiple access (OFDMA), which is a well-known high-capacity orthogonal multiple access (OMA) technique, NOMA offers a set of desirable benefits including greater spectrum efficiency. It has been verified in both theory [22] and system-level simulations [23] that NOMA outperforms OFDMA in terms of spectrum efficiency and machine connections.

Over the past few years, NOMA has attracted a great deal of attention from researchers trying to meet 5G requirements. Research trends in NOMA include diverse topics, for example, various performance analysis methods, fairness analysis, energy efficiency and user pairing. The key feature of NOMA is to serve multiple users at the same time and frequency resources but with different power domain multiplexing along with the significant spectral efficiency gain [24]. In NOMA systems, multiuser superposition coding is implemented in transmitters and successive interference cancellation (SIC) is adopted at receivers so that the receiver can recover their desired information from the multiplexed signals. Exploiting user diversities in power domain, NOMA is capable of accommodating more users on the same spectrum in comparison with the traditional orthogonal multiple access technologies [25]. However, aiming to improve the spectral efficiency (SE), cell throughput NOMA shows slightly increased receiver complexity [26].

1.3 Research Motivations

As mentioned above, over past few years M2M has attracted great attention from both research communities and business industries. To cellular operators, this growth of new M2M application has opened up a new market opportunity in the cellular industry. However, with the growth of need for M2M, challenges towards it has also increased. This research primarily propose a novel architecture for future M2M communications system that is capable of dealing with several challenges-energy inefficiency, extensive time delay as well as reduced throughput. As the ubiquitousness of current cellular network is a major drawback, managing this numerous amount of machines simultaneously and to cope up with the access loads, robustness in access technology will be required. Since existing multiple access technologies like- Time-division multiple access (TDMA), Frequency-division multiple access (FDMA), Code-division multiple access (CDMA), OFDMA are not an effective solution for the future M2M communication network, this research introduces NOMA as multiple access technique to serve heterogeneous machines to increase the average system throughput.

Despite the employment of high potential multiple access technique like NOMA, energy management of billions of machines in the M2M system simultaneously is a massive task. M2M devices are usually battery-driven and long battery life is crucial for them, especially for devices in remote areas, as there would be a huge amount of maintenance effort if their battery lives are short. To reduce signaling congestion vulnerabilities in the system architecture addition of clustering techniques and the CH reselection mechanism of improving the energy efficiency as well as the lifetime of machines is significantly important. Therefore, designing an M2M communication architectureincorporating clustering and energy based CH reselection method using hybrid TDMA-NOMA technology is of extreme significance.

1.4 Research Objectives

The main objective of this research is to propose an architecture for M2M communication over 5G cellular networks with aims to improve system throughput, energy efficiency, delay performance and machine lifetime. The proposed architecture incorporate *k*-means clustering technique and energy based CH reselection method for efficient energy and throughput utilization. As the multiple access technique, TDMA and NOMA are employed for CH-machines and CH-BS communications respectively. System performance will be evaluated considering perfect communication as well as under the newly developed 3D 5G wireless channel models. Impact of system parameters including number of machines, data size, cell radius, channel scenario and transmit power on simulation results are examined. Thus, the objectives of this thesis can be summarized as below.

- To propose a new architecture for M2M communications over cellular networks.
- To incorporate *k*-means clustering for machines as well as CH reselection method in order to balance the power consumption and increase battery life of machines.
- To integrate both TDMA and NOMA in the architecture for reducing communication delay.
- To evaluate the system performance in terms of energy usage, throughput, energy efficiency, lifetime of machines and communication delay with perfect communication and 3D 5G wireless channel models.

1.5 Organization of the Thesis

This Thesis book contains five chapters.

Chapter 2 provides an essential background on the basic architecture of M2M communications including its application, a comparative study on the major future design challenges. A comprehensive literature survey on the existing NOMA principle is also presented. Impacts of clustering in M2M communication and *k*-means clustering is discussed in brief.

Chapter 3 presents the proposed system model for M2M communication architecture along with mathematical expressions of the 3D channel model and the proposed hybrid TDMA-NOMA radio access technique.

Chapter 4 focuses on the simulation parameters and result analysis. Extensive simulations are carried out for evaluating the system performance considering the newly developed 3D 5G wireless channel models in terms of energy efficiency, life-time of machines and throughput. Impact of system parameters including number of machines, cell radius, transmit power and channel model on system performance are examined.

Chapter 5 concludes the thesis by summarizing the major findings, as well as identifying several potential research opportunities for the improvements and extensions of the proposed network architecture.

1.6 Chapter Summary

This chapter has identified the introduction and major challenges of M2M communication in 5G future cellular networks. Next, a brief discussion on NOMA is presented. A concise form of the research motivation and objectives is then provided. Finally, for the convenience of the readers in following this research, a chapter-wise outline of the thesis is presented.

Chapter 2

Background

This chapter studies the basic architecture and components of M2M network including typical applications. Afterwards, a brief overview of future challenges and design issues of M2M is presented. Furthermore, conventional NOMA technology and future challenges are discussed in detail. The chapter is finally concluded by presenting a brief discussion on clustering technique on M2M communications.

2.1 Introduction to M2M Communications

Internet technology has become a significant infrastructure by connecting anything from anywhere. With the introduction of M2M, the next generation IoT has to offer the facilities to connect multifarious objects together. M2M communicationsis defined by enormous real-time, versatile, omnipresent, dependable, and heterogeneous big data information related properties those are instrumental to the environment. To support M2M communications, cellular network is chosen as a fundamental component for its large-scale connectivity, appropriate mobility management as well as fast data rates [28]. The comprehensive connection of machines favor the emergence of gigantic M2M applications ranging from e-health, smart grids, smart homes as well as intelligent transportation systems [29].

2.1.1 Architecture and Components of M2M Communications

M2M communication refers to be a kind of communication technologies that comprises one or multiple entities with no or limited human support for measuring, gathering and delivering information to remote destinations. In recent wireless world, M2M traffic has become an increasingly important source of traffic in cellular networkfeaturing massive and ubiquitous connection, small packettransmissions, and diverse range of applications [30]. The European Telecommunications Standards Institute (ETSI), in contrast, has proposed a service-oriented M2M network architecture, which have been adopted worldwide for realizing M2M communications. According to ETSI specifications [31], Fig. 2.1 depicts a typical M2M network architecture. It consists of three main domains, namely the M2M device domain, M2M gateway, the communication network domain and the M2M application domain.

- **M2M Device Domain**: M2M devices are able to collect and aggregate data as well as transmit data autonomously. M2M devices can be either static (e.g., power meters in homes, machines in factory, etc.) or dynamic (e.g., fleet management devices in vehicles). M2M device domain provide connectivity between M2M Devices and M2M Gateways (e.g. personal area network). They consist of a large number of M2M machines and an M2M gateway to form an M2M area domain. Each M2M machineis very flexible and smartly equipped with some intelligent sensing technologies (e.g., wearable wireless node in an e-healthcare system) for real-time monitoring.

- **M2M Gateway**: Equipment that ensure M2M device's inter-working and interconnection to the communication network. Once monitoring data are sensed by M2M devices, they will make an intelligent decision and transmit the sensory data packets to the gateway in single hop or multihop patterns. After collecting the packets from all kind of M2M devices, the M2M gateway intelligently manages the packets and provides efficient paths for transmitting these packets to the remote back-end server via network domain.

- **M2M Communication Networks Domain**: It covers the communications between the M2M Gateway(s) and M2M application(s). Examples of M2M area networks mainly include personal area network technologies, such as IEEE 802.15, Ultra-wideband (UWB), Zigbee, and Bluetooth, or local networks, such as power line communication (PLC), Wi-Fi, Femtocell, and wireless M-BUS.In the network domain, the great success of wired networks (e. g., xDLS, and PLC) and the ubiquity of wireless networks (e.g., 3G cellular, WiMAX, and Wi-Fi) provide cost-effective and reliable channels for transmitting the sensory data packets from M2M area domain to server and application domain [32].

- **M2M Applications Domain**: It contains the middleware layer where data goes through various application services and is used by the specific business-processing engines. In the application domain, the back-end server is an important component for the whole M2M paradigm, which not only forms the data integration point for storing all sensory data from M2M area domain, but also provides these real-time data to a variety of M2M applications for remote monitoring management. For example, the typical utilizations are employments of global position system (GPS) data by traffic monitoring systems such as traffic court or reaction of a real-time system to its environment events.

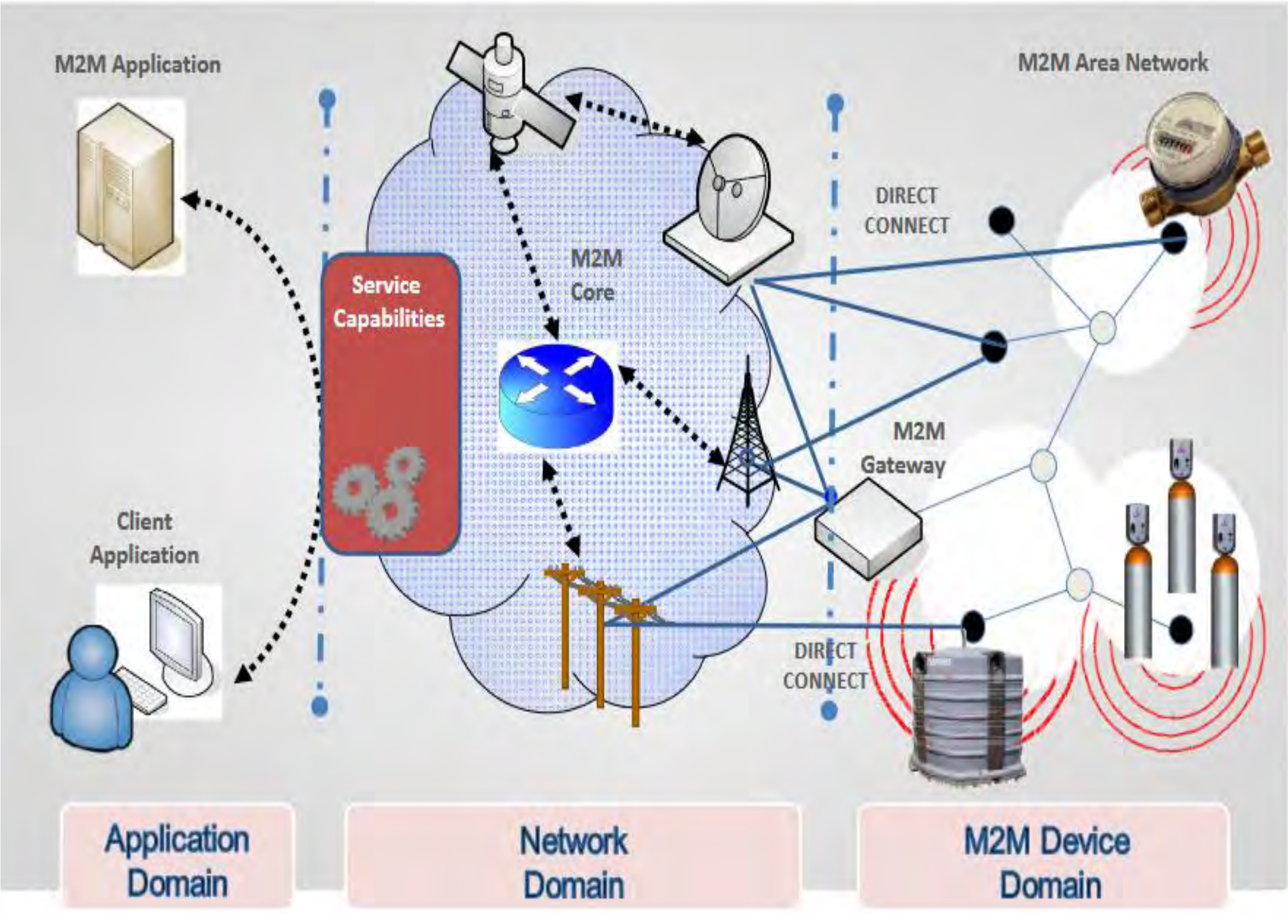

Fig. 2.1: Architecture of M2M system [33].

2.1.2 Machine-to-Machine Standardization

Current M2M markets are highly fragmented and most vertical M2M solutions have been designed independently and separately for each application. This rising market demands and newbusiness opportunities associated with M2M, different standardization activities are in progress to build M2M next generation proof, mainly from 3GPP, ETSI, and IEEE.

ETSI yields global ICT standards including fixed, mobile, radio, converged, broadcast, and internet technologies. M2M standardization work is conducted by the machine-to-machine communications technical committee (TC-M2M). ETSI focuses on the service middleware layer to be independent of access and network transmission technologies. It classifies service capabilities to provide common function required by different M2M applications [33].

3GPP is another key standardization body which features requirements for machine type communication (MTC). 3GPP identifies two MTC scenarios, namely, MTC devices communicating with one or more MTC servers and with other MTC devices. 3GPP introduces the key issues and solutions to fulfill the MTC service requirements. The key issues mainly focus on lack of IP addresses and congestion of control and data signals for a large number of MTC devices. The solutions try to resolve the key issues using IPv6 address or dual-stack address and group-based management for M2M devices [34].

Within the International Telecommunication Union–Telecommunication Standardization Sector (ITU-T), the Focus Group on the M2M service layer, establishedin 2012 and terminated in 2013, was responsible for studying the requirements and specifications for a common M2M service layer (including architecture, protocols, and API aspects) [35]. Such service layer is aimed to support different application domains, such as eHealth, smart grids, and industrial automation. The focus of the group was on eHealth (e.g., remote patient monitoring and ambient assisted living).

2.1.3 Applications of M2M Communications

M2M offers tremendous opportunities as well as unique challenges.M2M solutions are rolling out worldwide and across all industries-possibly being a key enabler of applications and services covering a broad range of vertical markets. M2M applications include intelligent transportation, healthcare, smart grid, manufacturing, supply and provisioning, utilities, transport, education-research and development, logistics etc. [36]. The applications of M2M cover wide range of sectors and the areas in which M2M is currently used are given below Table 2.1

Table 2.1: Applications of M2M communications

Domain	**Applications**
Security	Surveillances, Alarm systems, Access control, Car/driver security.
Tracking & Tracing	Fleet Management, Order Management, Pay as you drive, Asset Tracking, Navigation, Traffic information, Road tolling, Traffic optimization/steering.
Payment	Point of sales, Vending machines, Gaming machines.
Healthcare	Monitoring vital signs, Supporting the aged or handicapped, Web Access Telemedicine points, Remote diagnostics.
Smart meter	Power, Gas, Water, Heating, Grid control, Industrial metering, transmission and distribution network automation.
Manufacturing	Production chain monitoring and automation.

2.2 Challenges of M2M Communications in Future Cellular Networks

As there is a drastic change in number of users, M2M technology is besetting with several significant challenges. Major challenges of future M2M in cellular networks are such as- spectrum scarcity problem, signaling congestion, high energy consumption and many more. M2M devices are expected to generate a high signaling load on access networks while transmitting relatively small data per device [37]. Thus the resulting signaling overhead is a major concern for cellular network operators that needs to be addressed. This overhead signaling generated by huge number of devices can be minimized introducing M2M data aggregator which is also able to improve uplink transmission efficiency.

As most machines are battery-driven and are sensitive to power consumption, designing power saving mechanism to extend the lifetime of the devices and the whole network is significantly important. The use of gateway machines or clustering nearby machines are already proven as a great solution to reduce the overall transmission power of the system [38], [39]. A well designed multiple gateway assignment scheme and energy efficient clustering technique can be helpful in reducing the interference induced to the primary M2M devices in multi-user cognitive 5G system [40].

Adequate radio resource allocation is one of the critical design aspects of M2M to maintain proper QoS to the machines [41]. The large number of M2M data traffic in uplink transmission can cause shortage problem of radio resources if optimized radio resource management scheme are not followed [42]. In light of this, spectrum sharing in 5G networks ensures the coverage of M2M services everywhere and anytime. It can also support a large number of M2M devices with diverse applications and services. Furthermore, cognitive radio technology can be the key to employing opportunistic spectrum sharing for M2M devices in future 5G cellular network [43].

The rapid growth of M2M communications has created the risk of security vulnerabilities and attacks [44]. Since most M2M applications generate and transmit sensitive data between M2M nodes, unauthorized access should be strictly prohibited [45]. Therefore, robust protection framework should be implement to secure confidentiality and valid authentication of the M2M data information [46].

Additionally, unreliable and incorrect sensing and transmission due to wrong monitoring is hampering reliability of M2M communications [46]. As M2M architectures are becoming increasingly popular along with their diverse potential applications, several limitations in different domains of M2M architecture are generating vulnerabilities in communication [47]. As a result, there is no other option than designing a solid well investigated ideal M2M communication architecture that will be enough to provide smooth deployment of above discussed factors.

2.3 NOMA as Radio Access Technique

NOMA has become one of the promising radio access techniques for spectral performance enhancement in next-generation 5G cellular networks [48]. By providing superior performance in system capacity, spectrum sharing, latency and massive connectivity, NOMA has satisfied the ultimate requirements of 5G [49]. In differentiate to the conventional orthogonal multiple access schemes (e.g. TDMA, FDMA), NOMA simultaneously serves multiple users in the same time/frequency/code domain but allotting each user in different power domain [50]. NOMA shows effective solution by allotting dynamic power levels among users with various channel state information (CSI) [51]. At the transmitter site, all the individual information signals of multiple users are superimposed into a single waveform. While this superimposing operation NOMA ensures that the user with better channel condition is allocated with lower amount of total power and user with poor channel condition gets higher transmit power. On the other hand, at the receiver, SIC decodes the superimposed signals one by one starting with the strongest signal to weakest [52]. There are different types of NOMA techniques, including power-domain and code-domain. We consider the power domain NOMA as the multiple access scheme for our proposed architecture over 5G cellular networks.

In conventional 4G networks, as natural extension of OFDM is used where information for each user is assigned to a subset of subcarriers [53]. Conversely, NOMA allows the users to share same spectrum while transmission. Fig. 2.2 illustrates the spectrum sharing for OFDMA and NOMA for two users. It is vindicated by several researchers that NOMA outperforms other multiple access techniques in terms of throughput, fairness, energy and spectral efficiency [54].

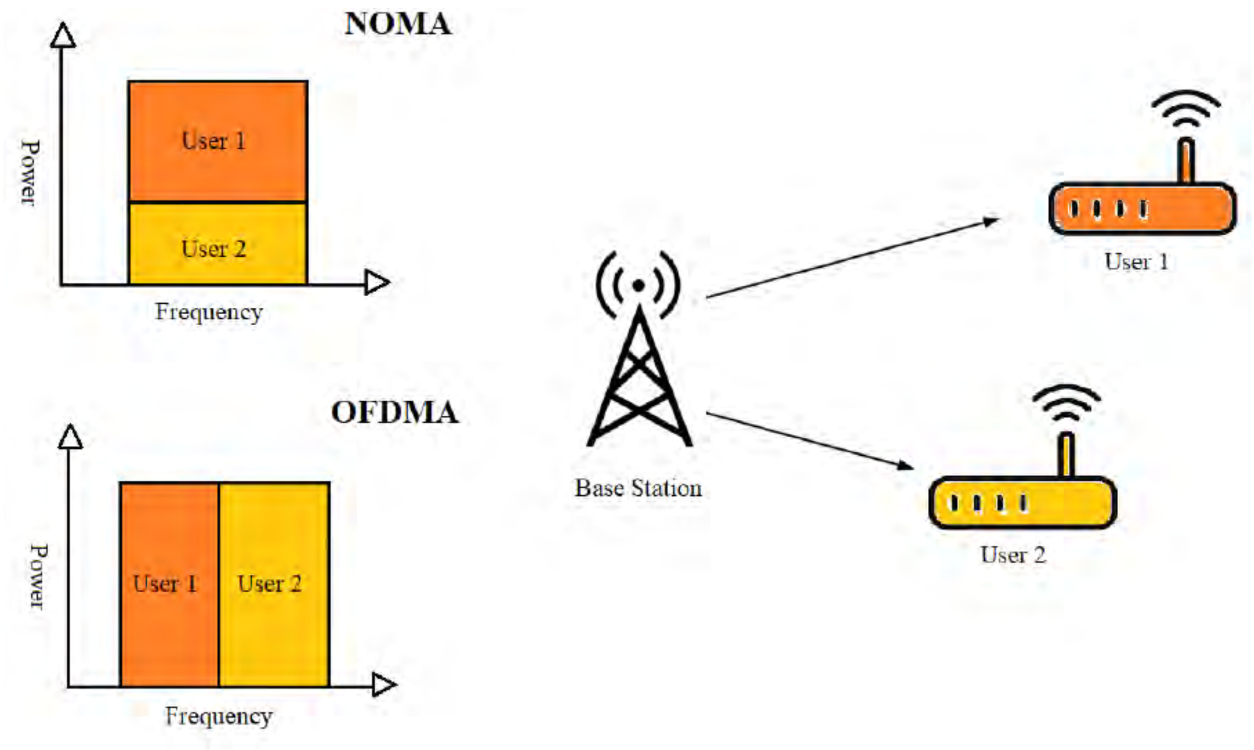

Fig. 2.2: Spectrum sharing for OFDMA and NOMA for two users.

2.3.1 NOMA for Downlink

In NOMA downlink, the base station superimposes the information waveforms for its serviced users [55]. Each user employs SIC to detect their own signals. Fig. 2.3 shows a BS and twousers with SIC receivers. In the network, it is assumed that the User 1 is the closest to the BS having good channel condition and User 2 is the farthest and has poor channel condition. In NOMA downlink, high transmit power is allocated to user located farther from the BS and the low power to the user closest to the BS. BS then superimposes both the signal splitting them into two different power domain and delivers the signal to receiver user. The receiver users receives the superimposed signal that contains the information for all users. Each user performs SIC to decode their desired signal. When a user performs SIC, from the superimposed signal, it decodes the strongest signal first. The user then subtracts the decoded signal from the superimposed received signal. The SIC receiver keeps iterating and subtracting the signals one by one until user finds its own signal. User located close to the BS can cancel the signals of the farther users. Since the signal of the farthest User contributes the most to the received signal, it will decode its own signal first.

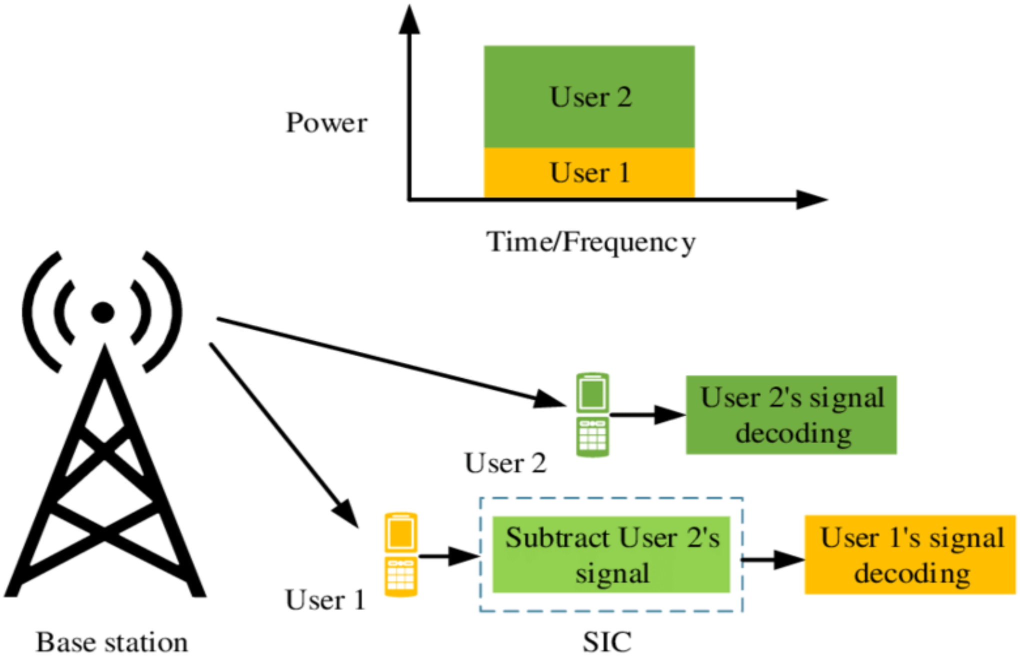

Fig. 2.3: Downlink NOMA for two users.

2.3.2 NOMA for Uplink

Uplink implementation of NOMA is slightly different than the downlink. Fig. 2.4 depicts a network that multiplexes users in the uplink using NOMA. This time, BS employs SIC in order to separate the user signals. In the uplink, users optimize their transmit powers according to their channel condition similar to the downlink. User 1 with higher channel condition is associated with lower transmit power and User 2 with lower channel condition is allocated with higher transmit power. However, assuming that the users are well distributed in the cell coverage, and the received power levels from different users are already well separated. This assumption is more natural from practical point of view, since power optimization requires connection between all the users which may be difficult to implement. At the receiver, the BS implements SIC. The first signal it decodes will be the signal from the nearest user [55].

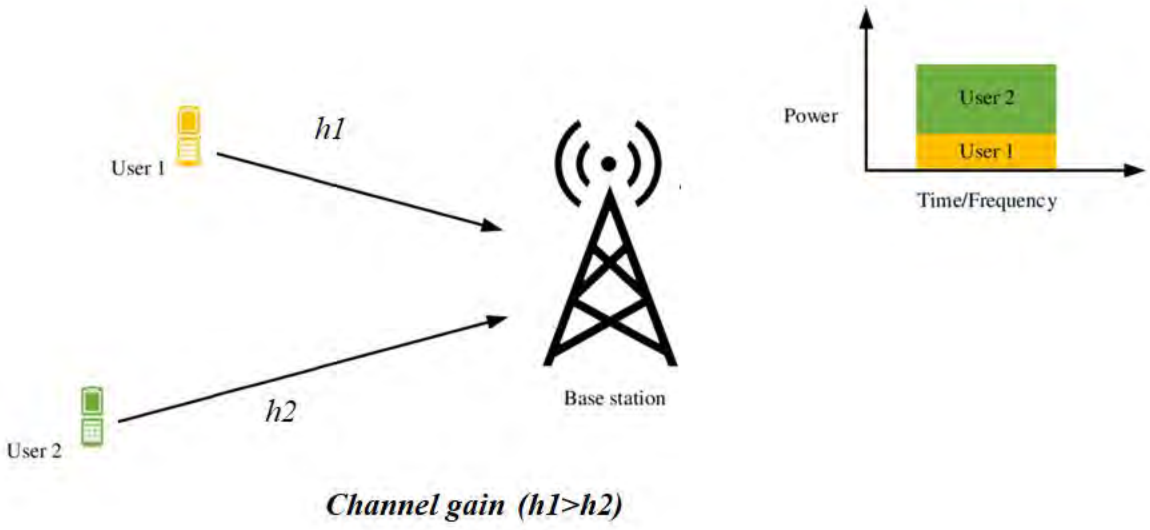

Fig. 2.4**:** Uplink NOMA for 2 users.

2.4 NOMA in M2M Communications

NOMA has recently attracted significant attention both in research world and industry by offering significant improvement in ubiquitous coverage, spectral efficiency and user experience [56]. NOMA is currently under consideration as a candidate radio access technology for the fifth generation (5G) wireless networks [57]. This research focuses on the power-domain NOMA that superposes multiple users into one signal by splitting them into various power domain at the transmitter side according to the user's channel condition. There are already some studies that introduce the NOMA scheme into M2M scenarios.

Recently, various advanced research works have been conducted on NOMA based M2M communication in cellular networks. For instance, to support explosive growth of machine connectivity in M2M networks, NOMA is considered as access scheme in [58]. It has been observed that by assigning accurate device pairing scheme for the NOMA-based transmissions, the reconfigurable scheme achieves better performance with NOMA. Recently millimeter wave based NOMA transmission has gained many researchers attention due to high directionality of millimeter wave and collision avoidance of NOMA [59]. Authors in [60], studied a novel millimeter wave NOMA transmission system for cellular M2M communications tailored for massive connectivity of IoT applications. Different systematic frameworks are being developed to study the throughput optimal system design for randomly arriving M2M devices in a cellular uplink [61]. Researches also carried out todesign an energy-efficient power control and time scheduling scheme in machine-type communications with NOMA including energy harvesting for achieving the optimal energy consumption [62]. An uplink energy minimization issue for an M2M enabled cellular network using NOMA is discussed by proposing an optimal power control and time scheduling scheme in [63].

Along with M2M, NOMA applications are also considered in wireless-powered communication networks (WPCN). Whereas, authors in [54] considered the application of NOMA for a wireless-powered uplink communication system, consisting single BS and multiple energy harvesting users. Moreover, performance of NOMA are also studied focusing on the overall system energy consumption in WPCN [64].

2.5 Clustering in M2M Communications

M2M communications is increasingly growing its popularity in present and future cellular networks for providing huge variety of available connectivity solutions, various ubiquitous services, global coverage provisioning etc. However according to several literature and surveys the future 5G cellular networks will be dealing with about 50 billion machine connectivity in 2020 [9]. As the result, M2M communication in future 5G cellular network will be facing massive challenges featuring this huge amount of machines efficiently and effectively.

In today's large-scale M2M communication system network, access requests generated by numerous heterogeneous machines raise the problem of fast energy drain, data congestion, collision etc. As mostly M2M devices are deployed in remote monitoring places, battery recharging or replacement is not frequent exercise in many cases. Undoubtedly, for battery life extension, energy efficient and have low power consumed machines are principle choices in M2M communication. In such scenarios, clustering is one of the most effective ways to reduce signaling overhead and energy consumption of machines. Clustering improves the energy efficiency as wellas the lifetime of machines [65]. Clustering increases the efficiency of data transmission by reducing the number of devices attempting to access the BS. Thus, it leads to reduced signal overheads among the network and save the energy of the whole system [66].

A Clustered network consists of a cluster head (CH) and a number of member machines. In each cluster group, member machines transmit their data to CH and then CH aggregates all the data and delivers to BS. Appropriately, the CHs drain more energy than cluster member because of the frequent packet transmission to the BS and cluster member nodes [67]. Clustering algorithms can be broadly classified into three categories, in the following subsections together with specific algorithms: Partitioning, Hierarchical, Density-based clustering [68].

- Partitioning Clustering: Partitioning clustering attempts to decompose a set of objects into k clusters such that the partitions optimize a certain criterion function. Each cluster is represented by the center of gravity (or centroid) of the cluster, e.g. k-means, or by the closest instance to the gravity center. Typically, k seeds are randomly selected and then a relocation scheme iteratively reassigns points between clusters to optimize the clustering criterion. The minimization of the square-error criterion-sum of squared Euclidean distances of points from their closest cluster centroid, is the most commonly used.
- Hierarchical Clustering: Hierarchical clustering methods impose a hierarchical structure on the data objects and their step-wise clusters, i.e. one extreme of the clustering structure is only one cluster containing all objects, the other extreme is a number of clusters which equals the number of objects. Hierarchical clusteringis a rigid procedure, since it is not possible to re-organize clusters established in a previous step. Example: Clustering Using Representatives (CURE), Balanced Iterative Reducing and Clustering Using Hierarchies (BIRCH).
- Density based Clustering: Density-based clustering methods group neighboring objects into clusters based on local density conditions rather than proximity between objects. These methods regard clusters as dense regions being separated by low density noisy regions. Similar to hierarchical and partitioning methods, density-based techniques encounter difficulties in high dimensional spaces because of the inherent scarcity of the feature space, which in turn, reduces any clustering tendency. Some representative examples of density based clustering algorithms are: Density-Based Spatial Clustering of Applications with Noise (DBSCAN), Density-based Clustering (DENCLUE).

Clustering have been proven to be an energy-efficient way for massive devices communications. Grouping machines into smaller clusters has been considered as one enabling technology for communications in dense M2M wireless networks [69]. Previous studies shows that a clustered network structure plays a significant role to accommodate the M2M traffic and reduce the random access delay under limited random access resource [70].

2.5.1 *k*-means Clustering Algorithm

k-means is one of the simplest unsupervised learning algorithms that solve the well-known clustering problem [71]. *k*-means delivers numerical, unsupervised, non-deterministic, iterative method in many practical applications and it is widely used for clustering large sets of data [72]. It is an iterative algorithm that works by partitioning the dataset into *k* pre-defined distinct non-overlapping clusters where each data point belongs to only one group. It attempts to create the inter-cluster data points as similar as possible while also keeping the clusters as different (far) as possible. Next, it assigns data points to a cluster such that the sum of the squared distance between the data points and the cluster's centroid (average mean of all the data points that belong to that cluster) is at the minimum.

The way *k*-means algorithm works is as follows:

1. Specify number of clusters *k*.
2. Initialize centroids by first shuffling the dataset and then randomly selecting *k* data points for the centroids without replacement.
3. Keep iterating until the position of centroids remain unchanged. i.e assignment of data points to clusters isn't changing.

- Use Euclidean distance formula to compute the sum of the squared distance between data points and all centroids.
- Assign each data point to its nearest centroid.
- Compute the centroids for the clusters by taking the average of the all data points that belong to each cluster.

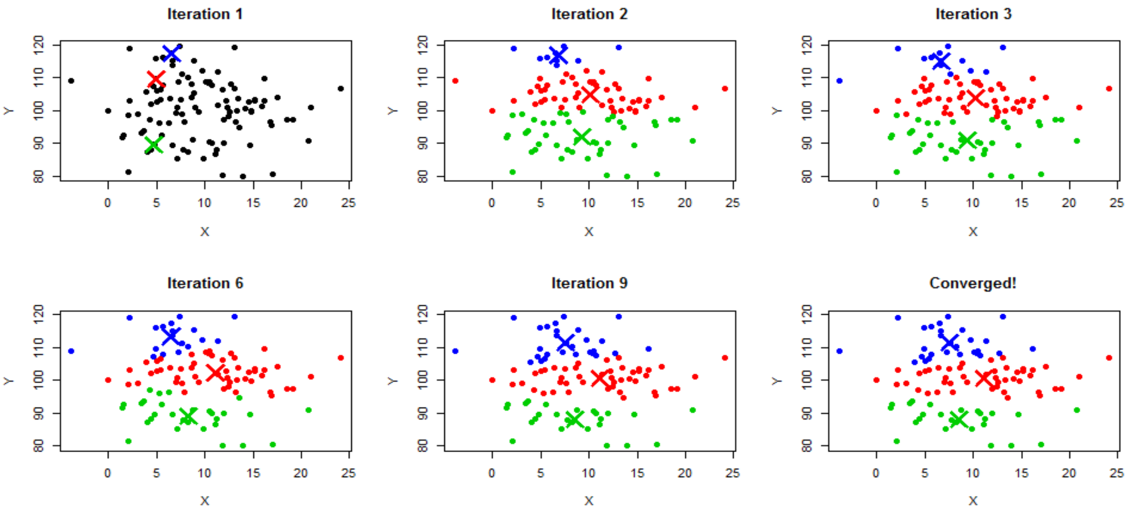

Fig. 2.5: *k*-means clustering illustration [71].

k-means clustering is a machine learning clustering technique used to simplify large datasets into smaller and organized datasets. Advantages that *k*-means clustering offers are listed below.

- **Simplicity:** It is facile to implement *k*-means and organizeinto optimal groups of data from large and complex data sets. The results are presented in an easy and simple manner.
- **Flexibility:** *k*-means algorithm can effectively alter to the changes. If there are any problems, adjusting the cluster segment will allow changes to easily occur on the algorithm.
- **Faster Operation:** *k*-means is suitable for a large number of datasets and it's computed much faster than the smaller dataset. It can also produce higher clusters.
- **Efficient:** *k*-means algorithm shows accuracy at segmenting the large data set. Its efficiency depends on the shape of the clusters. *k*-means work well in hyper-spherical clusters.
- **Accuracy**: *k* -means analysis improves clustering accuracy and ensures information about a particular problem domain is available. Modification of the *k*-means algorithm based on this information improves the accuracy of the clusters.

For *k*-means clustering to be effective, the number of clusters (*k*) has to be specified at the beginning of the algorithm. Sometimes it is difficult to predict the *k*-values or the number of clusters. It is also difficult to compare the quality of the produced clusters. *k*-means clustering sometimes gives varying results on different runs of an algorithm [73]. However, *k*-means is a widely used clustering algorithm in field of data mining across different disciplines over past few years [74]. In M2M communications *k*-means clustering has been proposed for cost-efficient deployment method for the SGM node scheme to improve the energy efficiency [75].

2.5.2 Cluster Head Reselection

Cluster-based networking has some benefits, especially forthe large-scale sensor networks, such as energy saving and scalability [76]. Each cluster consists of a primary cluster head and a number of cluster members. The CH is responsible for coordinating member M2M devices, collecting data from other machines and transmitting the aggregated data to the BS. CH spends higher amount of power while collecting data from member machines and forwarding aggregation packets to BS. Consequently, the machine that works as CH during whole operation time, energy of that machine gets exhausted faster than normal devices [77]. Therefore cluster head reselection is an effective way to reach the requirement of saving battery life of machines. The duty of cluster head is therefore divided into other member machines. After each transmission cycle total energy consumption should be calculated and the least consumed machine shall have the duty to be cluster head for the next transmission round. CH reselection method has been adopted in several literature and it is vindicated that CH reselection has longer the overall network lifetime [78].

2.6 Chapter Summary

An introduction to the architecture, applications and future challenges of M2M communication system has been presented in this chapter. This chapter also have briefly discussed the detailed NOMA working principle and its impact on M2M communication. Also the necessity of clustering with the applied *k*-mean clustering and cluster head reselection method has been discussed.

Chapter 3

Proposed Architecture for M2M Communication

This chapter focuses on the proposed neoteric architecture for M2M communication over the 5G cellular networks. The 3D channel models for 5G cellular network are presented. NOMA based power coding and successive interference cancellation (SIC) on CH and BS are described with mathematical expressions. The newly developed 3D 5G wireless channel models are also presented.

3.1 Network Model

A cellular network based M2M system is considered, where the machines are indexed by $\boldsymbol{M} = \{M_1, M_2, \ldots, M_N\}$, N denotes the total number of machines uniformly distributed in the coverage area. A schematic diagram of the proposed architecture is shown in Fig. 3.1. These machines are grouped in a number of clusters with their respective CHs. Let $\boldsymbol{M^X} = \{M_1^X, M_2^X, \ldots, M_n^X\}$ and $\boldsymbol{M^Y} = \{M_1^Y, M_2^Y, \ldots, M_n^Y\}$ denote the set of machines in X and Y cluster where M_i^X, M_i^Y to be their CH. It is assumed that the machines in a cluster are synchronized to each other. Machines in a cluster communicate with the machines of another cluster through their respective CHs and BS. For communication within a cluster (machines-CH), TDMA is proposed. Furthermore, communication between CH and BS, NOMA is proposed as multiple access technology. As shown in Fig. 3.1, for the uplink communication, machines M_1^X-M_n^X send their data to their CH M_i^X. The CH then collects and aggregates all the signal and forms NOMA frame by superimposing them into one signal by splitting them into specific power domain. The CH then sends the NOMA signal to BS. Afterwards, receiving the NOMA signal, BS performs SIC and separates each signal accordingly. BS then again superimposes the signals for forming the downlink NOMA frame and then transmits the signal. The receiving CH M_i^Y in the downlink then performs the SIC and forwards the data to its members M_1^Y-M_n^Y using another TDMA frame.

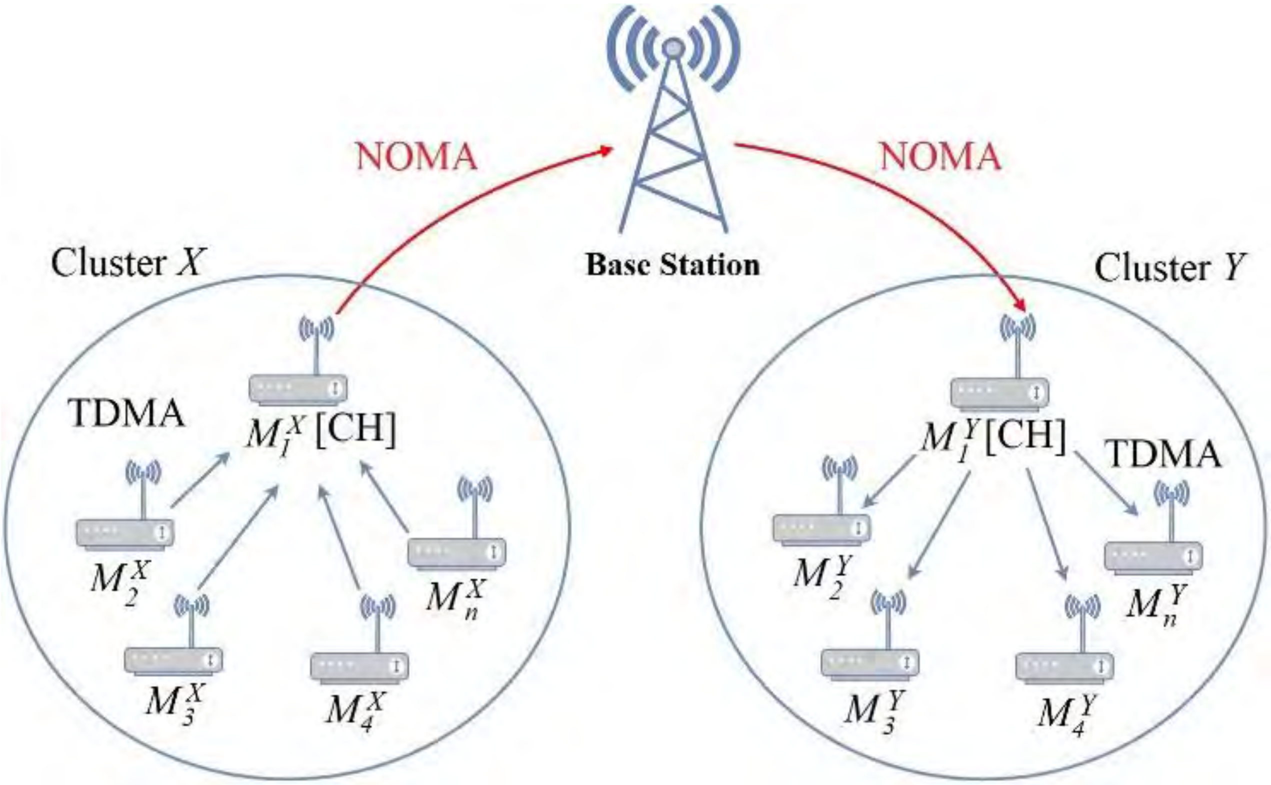

Fig. 3.1: Proposed M2M communication architecture.

3.1.1 3D Channel Models for 5G

The next generation 5G cellular network will environ a new spectrum band up to 100 GHz to meet the requirement of wide range of bandwidth channels. In Release 16, 3GPP has provided an initial 3D channel model which includes: 1) typical deployment scenarios for urban microcells (UMi) and urban macro cells (UMa), rural macro (RMa) area, Indoor and 2) A baseline model for incorporating path loss, shadow fading, line of sight probability, penetration and blockage models for the typical scenarios [79]. For the simulation of our proposed architecture we have used the 3D channel models to study the average throughput behavior of machines. For machine-CH communication, we consider the indoor office scenario (NLOS) and for CH-BS communication we consider, the UMi, UMa and RMa scenario. Path loss models for the 0.5-100 GHz band used in this thesis are given as below.

1) *Rural Macro (NLOS)*:

$$PL_{RMa-NLOS} = 161.04 + 7.1\, log_{10}(W) + 7.5\, log_{10}(h) - \left(24.37 - 3.7\left(\frac{h}{h_{BS}}\right)^{2}\right) log_{10}(h_{BS}) + \left(43.42 - 3.1\, log_{10}(h_{BS})\right) log_{10}(d_{3D}) - 3) + 20\, log_{10}(f_c) - (3.2(\; log_{10}(h_{UT})) - 4.97) \quad (3.1)$$

[h_{BS} = 35m, h_{UT}= 1.5-2.5 m]

2) Urban Macro (NLOS):

$$\mathrm{PL_{UMi-NLOS}} = 13.54 + 39.08\, \mathrm{log_{10}(d_{3D})} + 20\, \mathrm{log_{10}(f_c)} - 0.6\, (\mathrm{h_{UT}} - 1.5) \quad (3.2)$$

[h_{BS} = 25m, h_{UT}= 1.5-2.5 m]

3) Urban Micro (NLOS):

$$PL_{UMi-NLOS} = 35.3\, log_{10}(d_{3D}) + 22.4 + 21.3\, log_{10}(f_c) - 0.3\, (h_{UT} - 1.5) \quad (3.3)$$

[h_{BS} = 10m, h_{UT} = 1.5-2.5 m]

4) Indoor-Office (NLOS):

$$P_{InH-NLOS} = 38.3\, log_{10}(d_{3D}) + 17.30 + 24.9\, log_{10}(f_c) \quad (3.4)$$

[h_{BS} = 2-3m, h_{UT}= 1.5-2.5 m]

Here, h_{BS} denotes transmitter height of BS and h_{UT} denotes receiver height of user terminal (UT) or machine, f_c is the frequency in Hz, W is the average street width, h is the average building height and d_{3D} is the 3D distance between BS and machine in meters. Fig. 3.2 illustrates calculation scenario for d_{3D}.

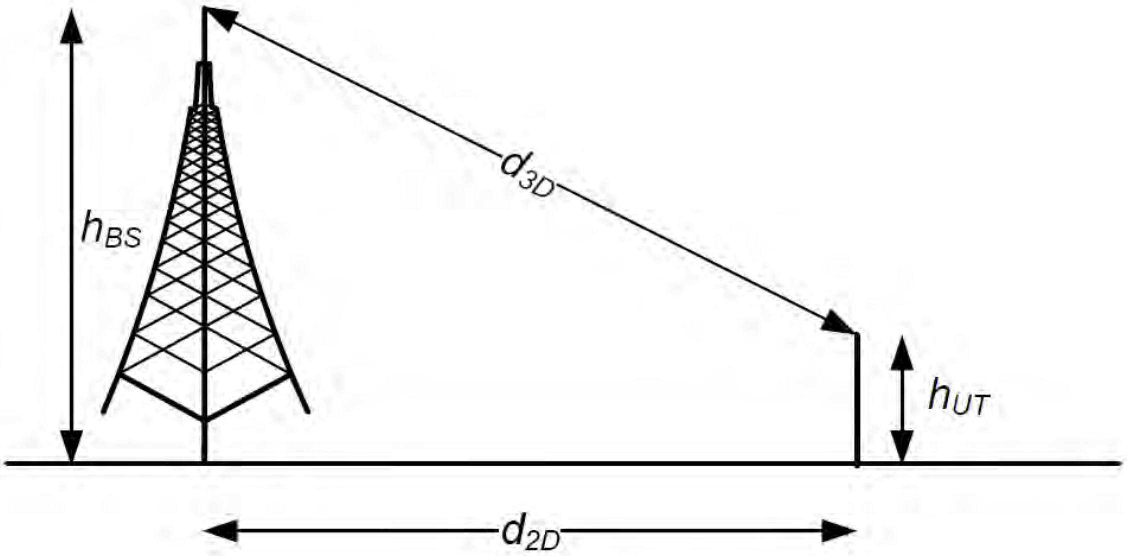

Fig. 3.2: Definition of d_{2D} and d_{3D} for user terminal [79].

3.1.2 Power Domain NOMA in CH and BS

The use of NOMA enables each user to have access the entire bandwidth and hence the bandwidth resources allocated to the users with poor channel conditions can still be accessed by the users with strong channel conditions, which significantly improves the spectral efficiency. In this thesis, we propose a NOMA power allocation as presented below.

Step 1: Compute the channel gain set $\boldsymbol{H}^{\boldsymbol{x}} = \{h_1^x, h_2^x, \dots, h_n^x\}$ for *n* number of machines.

Step 2: Arrange the machines into a new set $\boldsymbol{M}^{\boldsymbol{x}'}$ in descending order with channel gain values, that is, $\boldsymbol{M}^{\boldsymbol{x}'} = \{M_1^{x'}, M_2^{x'}, \dots, M_n^{x'}\}$, where, $h_i^{x'}$>$h_j^{x'}$ for *i*<*j*.

Step 3: Set total transmit power P_T for *n* machines. Divide P_T into *n* number of factions forming the set $\boldsymbol{P}_T^x = \{P_1^x, P_2^x, \dots, P_n^x\}$, P_i^x is the *i*th fraction of $\boldsymbol{P}_T$, *i*=1,2,….,*n*.

Step 4: Rearrange the set $\boldsymbol{P}_{\boldsymbol{T}}^{\boldsymbol{x}}$ in ascending order and form.

$\boldsymbol{P}_{\boldsymbol{T}}^{x\prime} = \{P_1^{x\prime}, P_2^{x\prime}, \dots, P_n^{x\prime}\}$, where $P_i^{x\prime} < P_j^{x\prime}$ for $i<j$.

3.2 Description of the Proposed System Architecture

3.2.1 Cluster Formation

To establish the communication system between BS and machines, BS needs to be aware of each machine's location. In first step, machines send their location information to BS using their respective TDMA timeslots for cluster *X*. Next, after receiving all the location information from the machines, BS executes *k*-mean clustering algorithm to arrange them into clusters with respective cluster head. Then according to the algorithm result, BS informs machines about their individual cluster group and CH using a single TDMA timeslot.

k-means clustering algorithm works as follows:

k-means algorithm is the simplest and fast working clustering method which is also inexpensive to implement and robust in nature. At first step, *k* number of centroids are randomly selected by the BS. Next, Euclidean distances of all the machines from the *k* centroids are calculated. After that, BS selects the respective nearest centroid for all the machines and then they are assigned to a cluster corresponding to the nearest centroid. Considering the location of each member in a cluster, the mean value of location is calculated. This mean value is the new location of the centroid of that cluster. Next, BS measures distances of all the machines to the new centroids and continue the process as explained above. After several iterations, the centroids locations do not change further and thus final cluster groups are formed as shown in Fig. 3.3

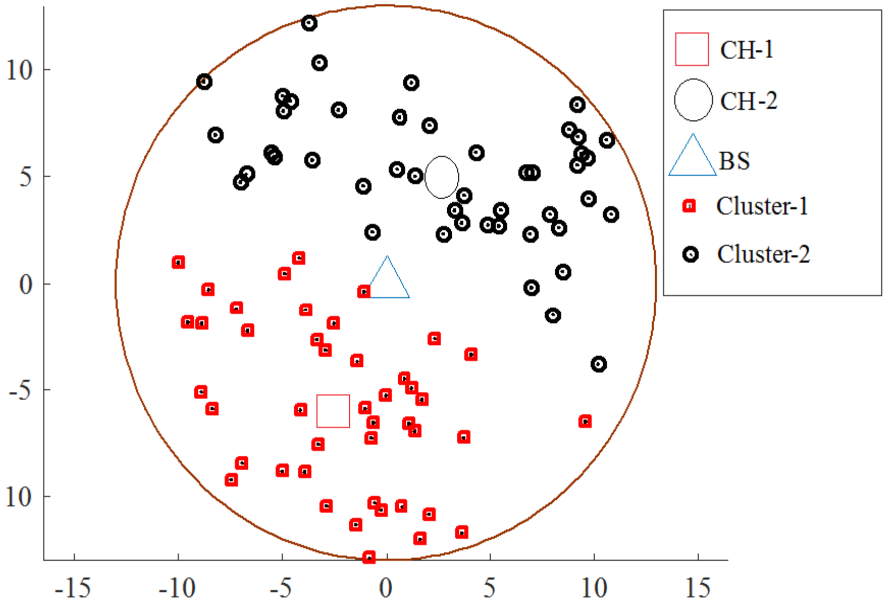

Fig. 3.3: Fixed position of machines in the final stage of *k*-mean clustering algorithm.

3.2.2 Uplink Data Transmission: Machine to CH

For the uplink communication between CH and member machines, we consider TDMA frame. Also, we assume that all machines transmit data in every transmission cycle. First, CH sends the transmission time detail information to the machines in a single timeslot. According to the scheduled transmission time, each machine transmits its data to CH using TDMA timeslot as shown in Fig. 3.4 TDMA time slots in machine to CH link are numbered as T_i^{mc}, where *i*=1,2,3,….,n.

From machine to CH						
Timeslots	T_1^{mc}	T_2^{mc}	T_3^{mc}	T_4^{mc}	…………………………	T_n^{mc}
Machine	M_2^X	M_3^X	M_4^X	M_5^X		M_n^X
Type of information	Data	Data	Data	Data		Data

Fig. 3.4: TDMA frame for data transmission in uplink from machine to CH.

We assume Indoor-office channel scenario in machine to CH link and calculate path loss by taking 3D distance from machine to CH. Path loss in machine to CH link is denoted by P_L^m and shadow fading is σ_m. The signal receive power P_r^m in machine-CH link can be written as

$$P_r^m = P_t^m - P_L^m + \sigma_m \tag{3.5}$$

Where P_t^m represents the transmit power of machine. Thus, the signal to noise and interference ratio (*SINR*) of machines in this machine-CH link $SINR_i^m$ will be

$$SINR_i^m = \frac{P_{ri}^m}{\sum_{j=M\text{-}N}^{M} P_{rj}^m + P_N} \tag{3.6}$$

According to Shannon's channel capacity theorem, the channel capacity of machines, C_i^m can be calculated as

$$C_i^m = B_w * log_2[1 + SINR_i^m] \tag{3.7}$$

Where B_w denotes the channel bandwidth. For the data transmission from machine-CH link and power consumption by circuitry is denoted by P_c. Overall energy consumption E_c^m for each machine can be expressed as

$$E_c^m = (P_c\, t_c + P_t^m t_m) \tag{3.8}$$

Where t_c is the time when machine is in on mode and t_m is the time to transmit data packet. Energy efficiency of the machines EE^m can be written as

$$EE^m = \frac{C_i^m}{E_c^m} \tag{3.9}$$

3.2.3 Uplink Data Transmission: CH to BS

NOMA is considered as the access technology for the uplink data transmission. CH collects and aggregates all the data coming from member machines. After that, CH allots them into different power domain considering their channel gain and then superimposes into one NOMA signal. The machine with higher channel gain sends strong signal to CH and lower channel gain machine sends weak signal. CH assigns higher power to machines with lower channel gain and lower power for machines with higher channel gain. In this step, the total transmission power from CH-BS link is considered as P_T^C and it is the sum of transmit powers allocated for each machine's data signal.

$$P_T^C = P_1^m + P_2^m + \cdots \ldots\ldots + P_n^m \tag{3.10}$$

Path loss in CH-BS link is denoted by P_L^C and shadow fading is σ_c. The receive power of signal transmitted by CH in dBm can be expressed as below

$$P_R^C = P_T^C - P_L^C + \sigma_c \tag{3.11}$$

$$E_i^C = (P_T^C T_c + P_C t_c') \tag{3.12}$$

where T_c is the total transmission time all the data packets and t_c is the time when the CH machine remains on mode. E_i^C is the total energy consumption in CH.

BS receives the NOMA signal from CH and performs successive interference cancellation (SIC) to decode the signal. Therefore, getting the superimposed NOMA signal BS decodes the strongest signal first by calculating signal-to-interference and noise ratio (SINR) and considering other signal as noise. After decoding each signal from the NOMA signal, BS subtracts that signal from the total signal. The weakest signal having the lowest SINR is decoded at the last.

3.2.4 Downlink Data Transmission: BS to CH and CH to Machine

We also consider NOMA for the downlink data transmission from BS to CH. BS superimposes each signal into one NOMA signal according to their receiver machine's channel gain and allots different power level to each signal. Then receiving the superimposed NOMA signal, CH decodes each signal sequentially using SIC and subtracts the decoded signal from received NOMA signal. After subtracting each signal CH then delivers the signal to its destination machine using the TDMA timeslot as shown in Fig. 3.5, where timeslots from CH to machine is denoted by T_i^{cm} .

From CH to machine					
Timeslots	T_1^{cm}	T_2^{cm}	T_3^{cm}	………………….	T_n^{cm}
Machine	M_2^Y	M_3^Y	M_4^Y		M_n^Y
Type of information	Data	Data	Data		Data

Fig. 3.5: TDMA frame for data transmission in downlink from CH to machine.

3.2.5 CH Reselection

CH reselection is a vital factor for the proposed M2M architecture. It is apparent that, as majorities of the operation is accomplished by CH, its battery may drain faster than other member machines. Therefore, to balance the battery life of machines, it is necessary to rotate the duty of CH among the member machines. After each transmission round, CH will be reselected depending upon their remaining energy. Each machine will send their energy information to BS using a TDMA frame as shown in Fig 3.6, where timeslots from machine to BS is denoted by T_2^{mb}. Consequently, the machine having high energy will have higher probability to become CH in next transmission round. Furthermore, BS will deliver the new cluster information to all the machines using a single timeslot.

From machine to BS				
Timeslots	T_1^{mb}	T_2^{mb}	………………………	T_n^{mb}
Machine	M_1^X	M_2^X		M_n^X
Type of information	Remaining energy	Remaining energy		Remaining energy

Fig. 3.6: TDMA frame for energy information in uplink from machine to BS.

3.3 Chapter Summary

This chapter explains the proposed M2M communication architecture in brief including the mathematical expression and theoretical explanation. Clustering algorithm including CH reselection method is interpreted clearly along with diagram. Each communication steps including TDMA frames are illustrated and described in detail. This chapter overviews the proposed system architecture and all the key parameters that are considered.

Chapter 4

Simulation and Analysis

This chapter explains the simulation results considering no channel model and incorporating newly developed 3D 5G wireless channel models. Performance of the proposed architecture is discussed in terms of energy efficiency and delay through extensive simulations. The simulations are also illustrated for evaluating the system performance considering the newly developed 3D 5G wireless channel models in terms of energy efficiency, life-time of machines and throughput.

4.1 Simulation Setup

To evaluate the performance of the proposed architecture of M2M communication, extensive simulations are carried out by developing a MATLAB based simulation platform. For the simulations, we considered two cluster groups consisting of static machines uniformly distributed in a cell of 100 meter radius area with a BS at the center. One of the cluster groups transmits data in uplink to the BS while the other one receives data in the downlink from the BS. We have assumed 100 mW transmit power for machines and each machine has 100 joule energy storage capacity. On the other hand, we consider, 1 Mbps data transmission speed for machine-CH whereas 500 kbps data speed for CH-BS link. The performance of the proposed architecture is also compared with the counterpart having no CH reselection mechanism [80]. Unless otherwise specified, data file size for transmission is assumed 1Mb. Table: 4.1 in the next page summarizes the key parameters for the performance analysis of the proposed architecture of M2M communication considering newly developed 3D 5G wireless channel models.

Table 4.1: Simulation Parameters

Parameter	**Values**
Cell Radius	100, 500, 1000 meter
Frequency (f_c)	2 GHz
Bandwidth (B_w)	180 kHz
Path loss model	Indoor-office, Urban micro, Urban macro, Rural macro
Shadowing (σ)	8.03, 7.8 db
Noise Power (P_N)	$-174+20\log10\ (B_w)$
Transmit power (CH-BS)	100-1000 mW
Circuit Power (P_C)	3mW
Data Size	100, 500 Bits
Total Energy	100 Joule

4.2 Result Analysis Considering Perfect Communication

Fig. 4.1 demonstrates the remaining energy of the machines in uplink for various transmission rounds for the proposed architecture with CH reselection mechanism. For the simulations, we consider 5 machines in each cluster group. For the convenience of comparison, simulation results for architecture having no CH reselection mechanism is shown in Fig. 4.2. From Fig. 4.1, it can be noticed that CH reselection shows major impact on the remaining energy of machines after various transmission cycle. The simulation result proves that the proposed CH reselection method can balance energy consumption efficiently among the machines and increase their overall life-time. On the other hand, Fig. 4.2 shows, keeping the same CH (machine 5) for all transmission rounds drains out the energy of CH quickly. As a result, it becomes a dead machine and halts the total communication procedure after 21st transmission round. This phenomena occurs due to continuous increase of energy load on the same CH in every transmission cycle.

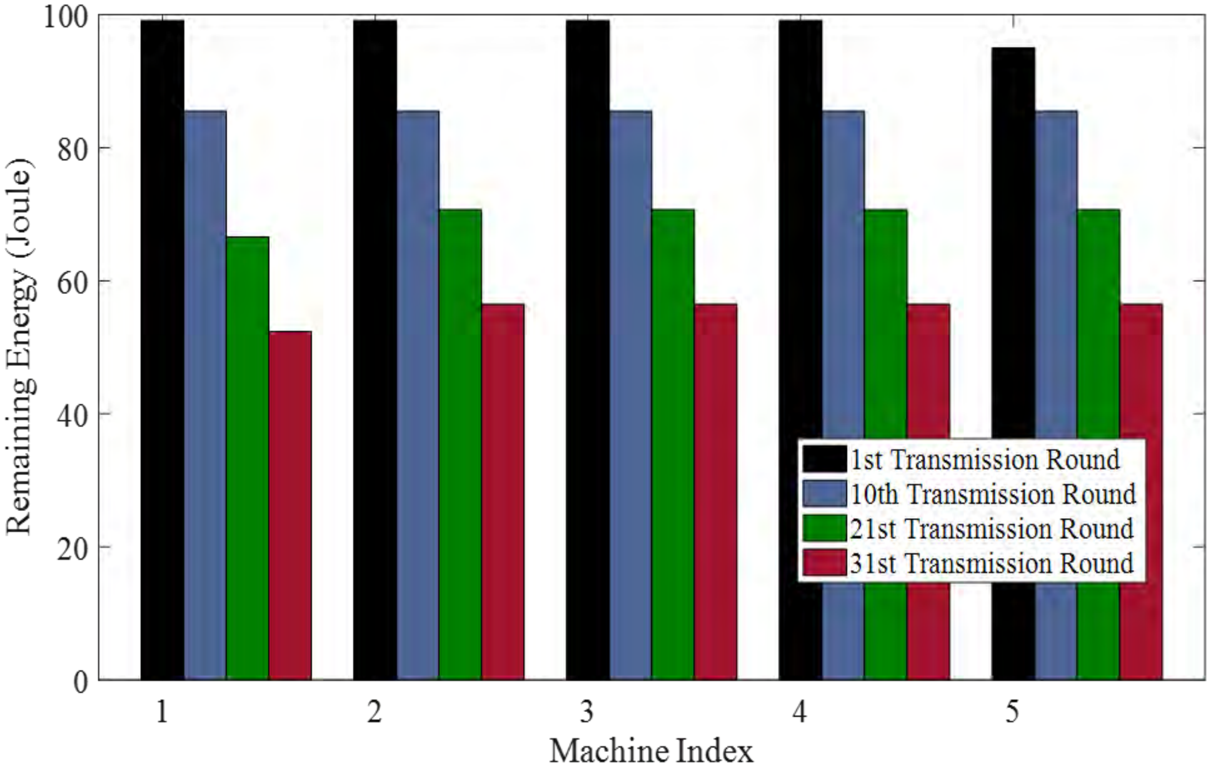

Fig. 4.1: Remaining energy of machines in uplink for the proposed architecture with CH reselection.

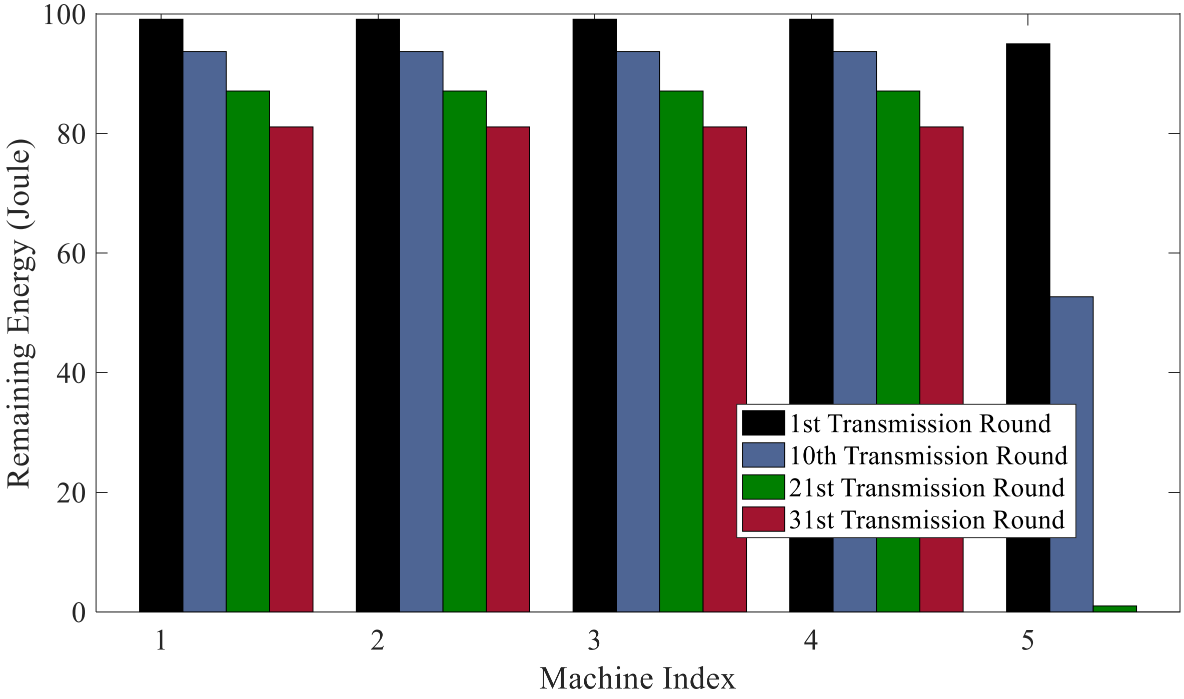

Fig. 4.2: Remaining energy of machines in uplink without CH reselection.

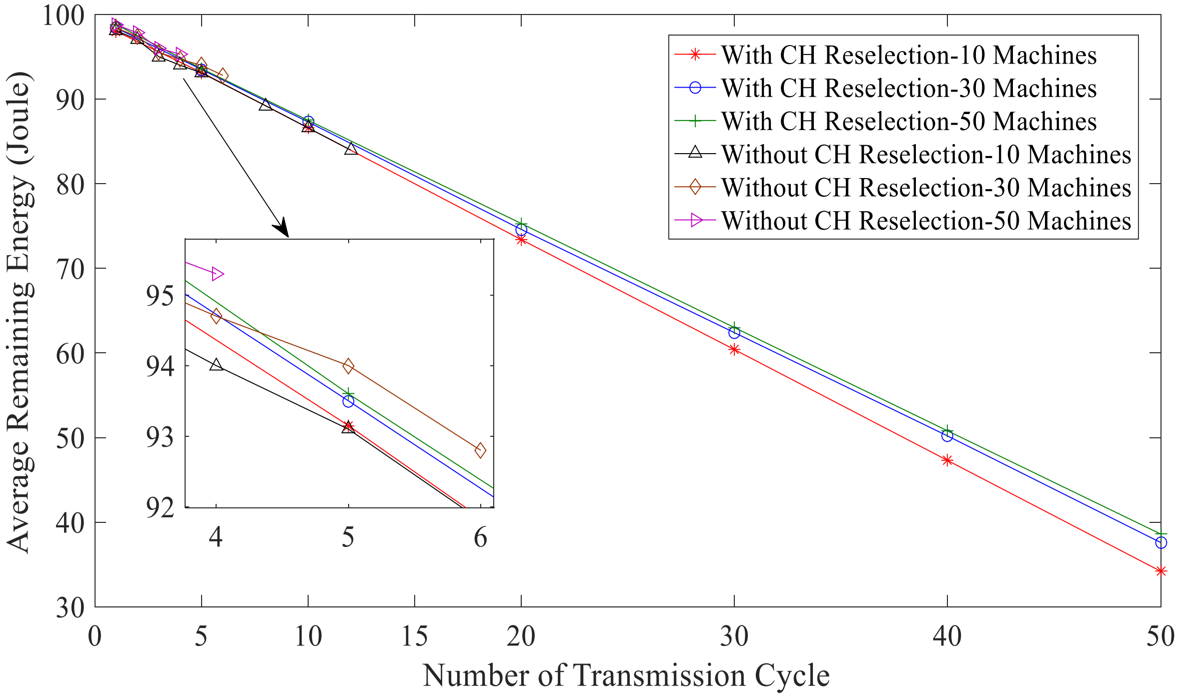

Fig. 4.3: Average remaining energy of machines at the end of transmission cycle with and without CH reselection.

Next, Fig. 4.3 compares the average remaining energy with and without CH reselection mechanism. Simulations are performed considering 3 scenarios for 10, 30 and 50 machines in each cluster. Here, without CH reselection, as the energy of CH drains out very quickly, only few transmission cycles can run. As evidently, in the figure, maximum number of transmission cycles for 10, 30 and 50 machines are 12, 5 and 3 respectively. Whereas, for the proposed architecture with CH reselection, machines and CH can run up to significantly higher number of transmission rounds. It can also be identified that as the number of machines per cluster increases, their average remaining energy also increases in the proposed architecture. This occurs because the machines balance the energy load among themselves and as a result, the average remaining energy increases.

Fig. 4.4 illustrates the number of maximum transmission cycle with the number of machines per cluster. Results are presented considering two different file sizes, namely, 1Mb and 500kb. Without CH reselection, number of maximum transmission cycle decreases with the increase in the number of machines per cluster. However for the proposed architecture with CH reselection, there is a random variation in transmission cycle. The reason behind this is the probability of reselection of a machine as CH changes with the increase in the number of machines per cluster as well as the remaining energy after each transmission cycle. Consequently, number of maximum transmission cycle fluctuates. On the other hand, when the data size is 500kb, network runs more transmission cycle than that of with data size 1Mb. This is because, a small amount of data takes less time and energy to transmit.

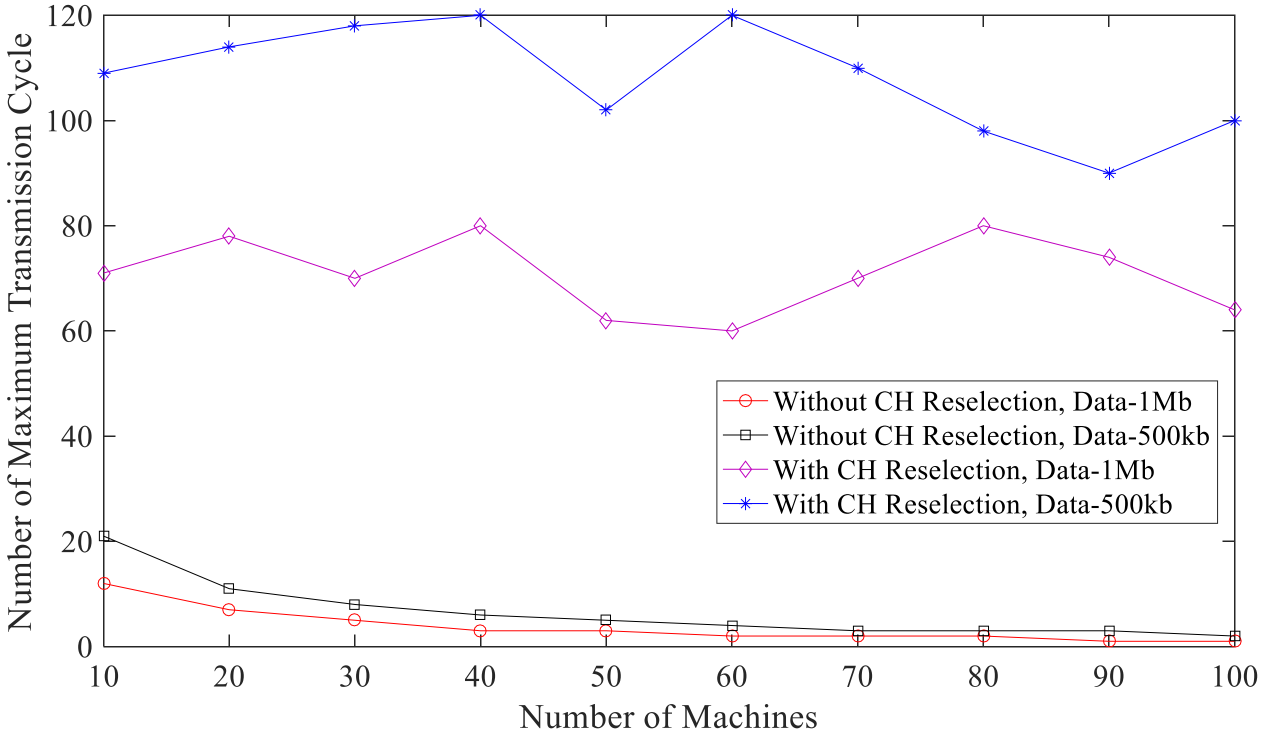

Fig. 4.4: Maximum transmission cycle varying with number of machines.

Fig. 4.5 demonstrates the variation in average remaining energy with the number of machines per cluster for three different data sizes - 0.5Mb, 1Mb and 2Mb. Here, the average remaining energy is calculated from the remaining energy in machines at the end of maximum transmission cycle as shown in Fig. 4.4. From the Fig. 4.5, it can be observed that for 0.5Mb data, the average remaining energy after the last cycle is mostly lower than that with 1Mb and 2Mb data size. The reason behind this difference is when the data size is small, machines take less amount of time and consumes less energy to transmit. Consequently, with the smaller size of data packet, machines can run a higher number of maximum transmission cycle resulting in a lower remaining energy. On the contrary, when the data size is large, machines run up to a less number of transmission cycle and because of that the average remaining energy stays higher. This Fig. 4.4 is also supported by the findings in Fig. 4.5.

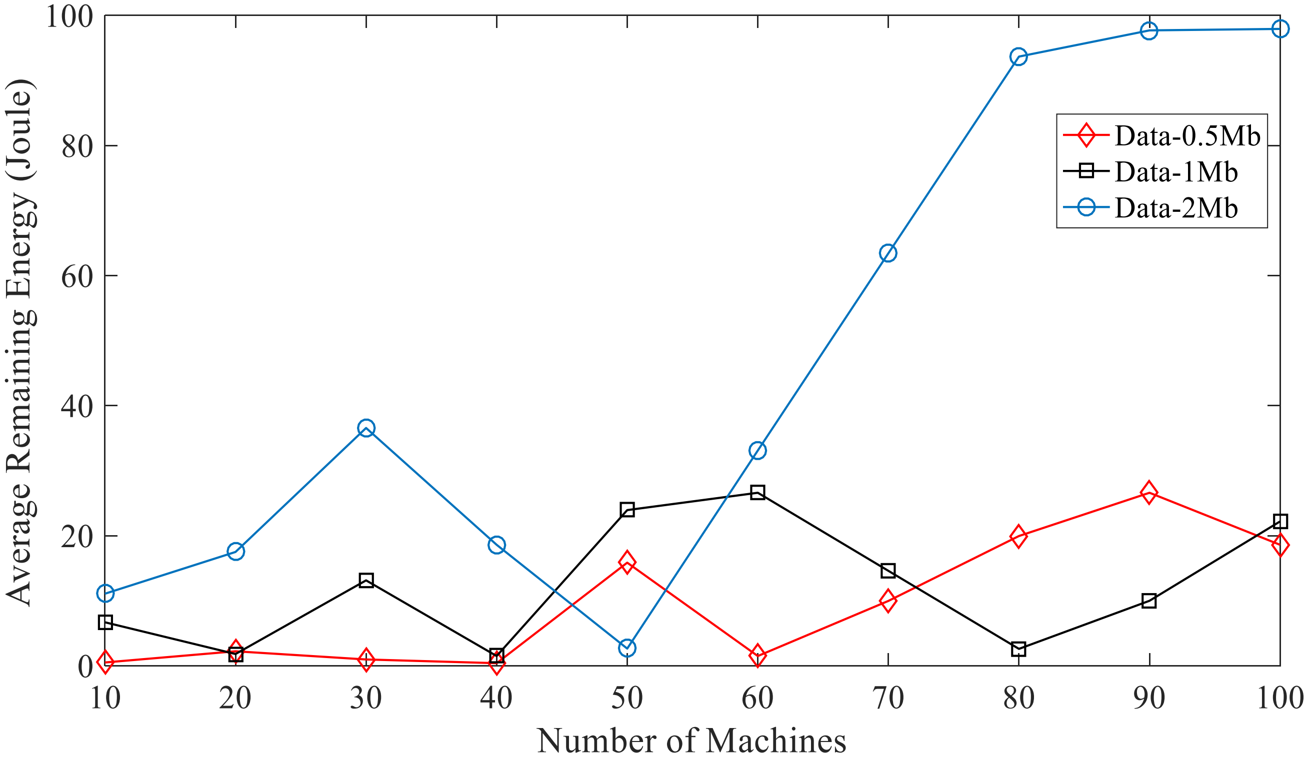

Fig. 4.5: Remaining energy varying up to maximum transmission cycle.

On the other hand, Fig. 4.6 illustrates the average delay required for a data packet to be transmitted in the uplink from a source machine to a destination machine in downlink for TDMA-TDMA and TDMA-NOMA based network architecture. In TDMA-TDMA based network, both the machine-CH and CH-BS links are TDMA based. It is evident that the proposed TDMA-NOMA based architecture has significantly lower time delay than the TDMA-TDMA based system. Moreover, with the increase in the number of machines, TDMA frame gets longer. That is why the gap between the proposed TDMA-NOMA and counterpart TDMA-TDMA based network increases with the number of machines. The main cause is that NOMA delivers all the data in the same timeslot while TDMA sends each machine's data using separate timeslots causing more delay.

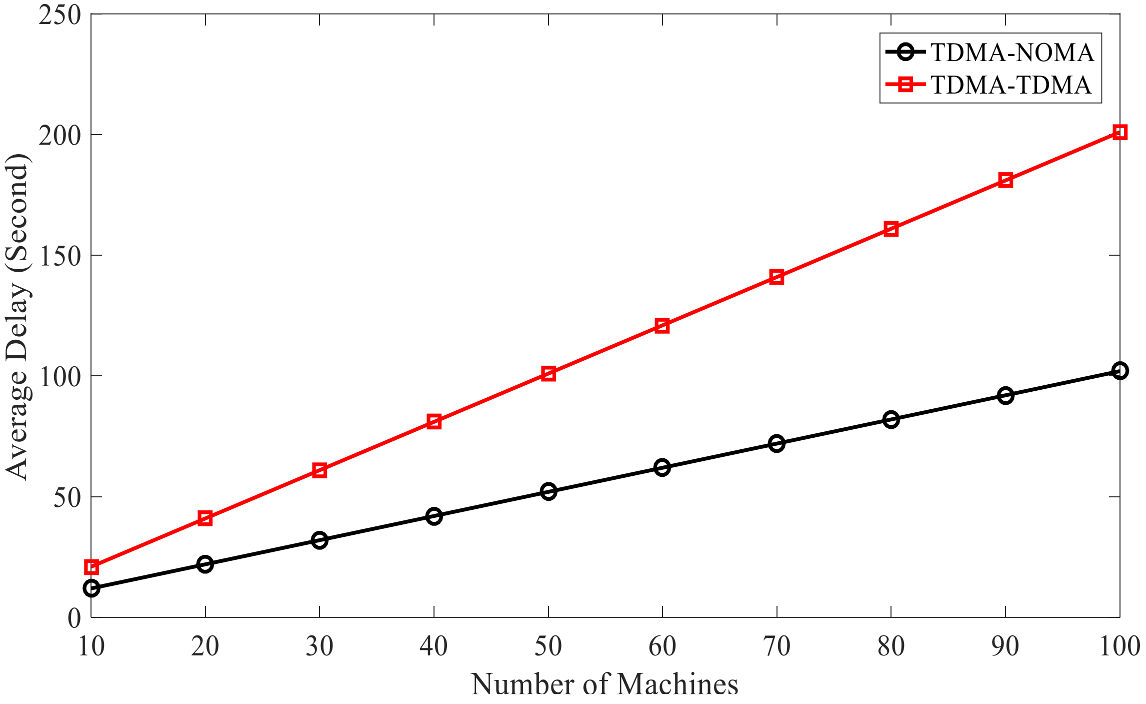

Fig. 4.6: Average delay of TDMA-NOMA and TDMA-TDMA.

4.3 Result Analysis Considering 3D 5G Wireless Channel

Fig. 4.7 demonstrates the average uplink throughput for the proposed architecture with and without machine clustering mechanism. Results are presented by taking average uplink throughput of various number of machines per cluster in machine-CH, CH-BS and direct machine-BS link. It is evident that clustering has major impact on system throughput. In the system with clustering, machines achieve significantly better throughput than without clustering system. This result explains that when machines communicate directly with BS using TDMA, signals has to travel long way and there remains high signaling interference and fading. Additionally, this leads to lower SNR and throughput. On the other hand, in the clustered network, throughput in machine-CH is quite high because there is no signaling interference as we are using TDMA and also the distance between CH and machines are less which causes low SNR and high throughput. On the contrary, SINR in CH-BS link significantly decreases with increase in number of machines and its signaling interference which also decreases the throughput. This happens because with the increase in number of machines, signaling interference also increases and this leads to lower SINR and low throughput.

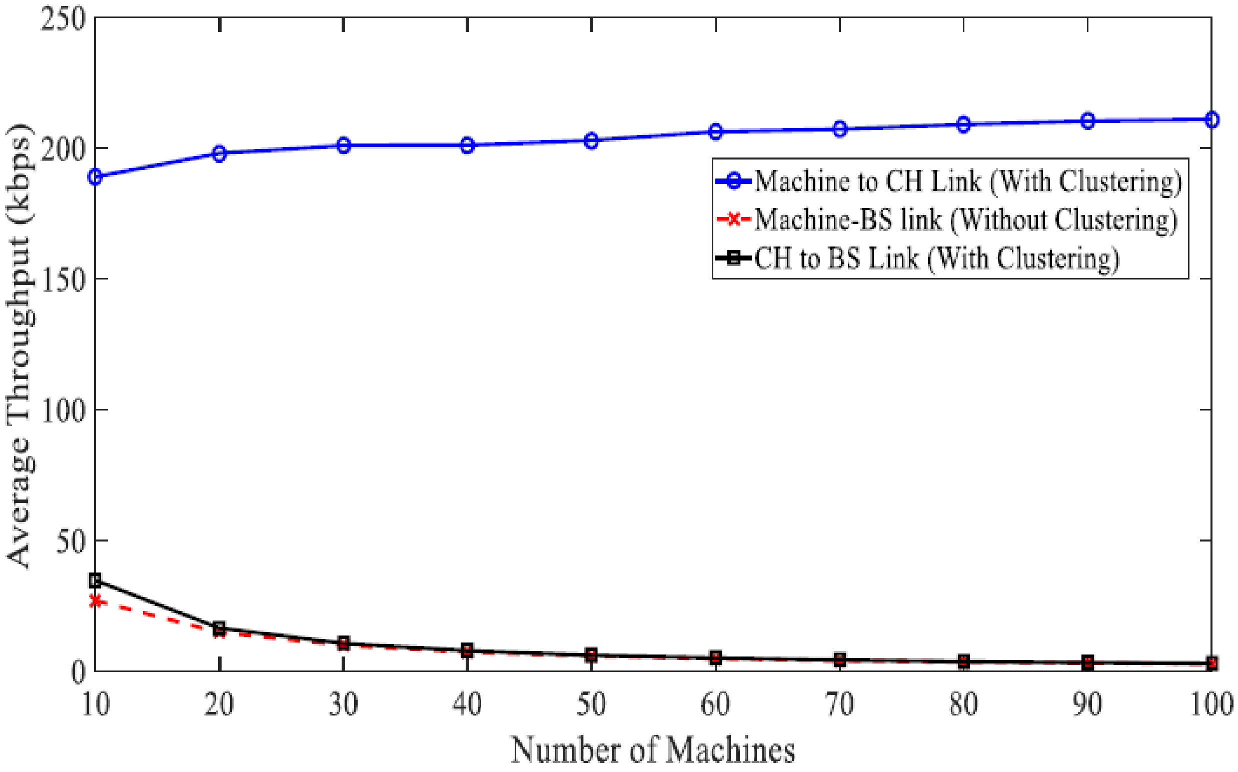

Fig. 4.7: Average Throughput varying with number of machines.

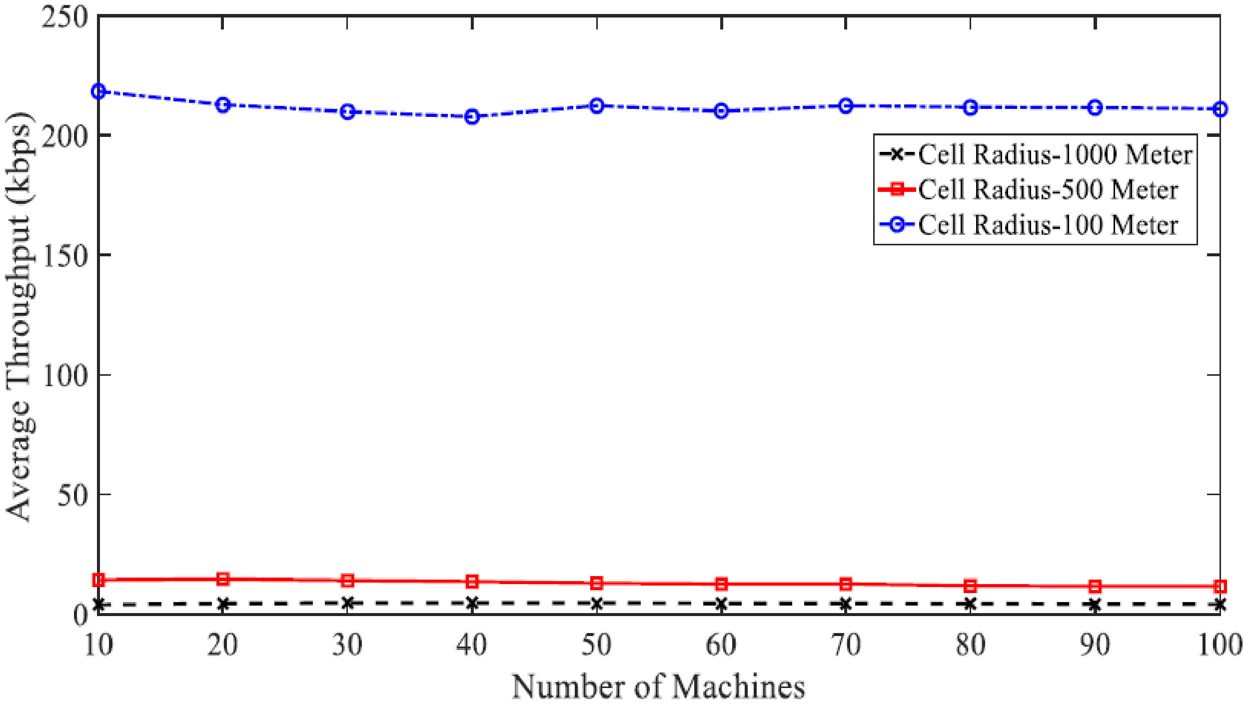

Fig. 4.8: Average throughput of machines varying with cell radius.

Fig. 4.8 illustrates the average throughput with number of machines per cluster altering with different cell radius. Results are presented considering 100, 500 and 1000 meter cell area and indoor office-Urban micro hybrid channel scenario in the uplink. From Fig. 4.8, it can be highlighted that machines in a small cell area achieve significantly better throughput performance than that in large cell area. In large cell area, machines experience high path loss that minimizes the receive power of signal. Consequently, this results in low SINR and low throughput value. However, in a small cell area, lower path loss produces high SINR and throughput.

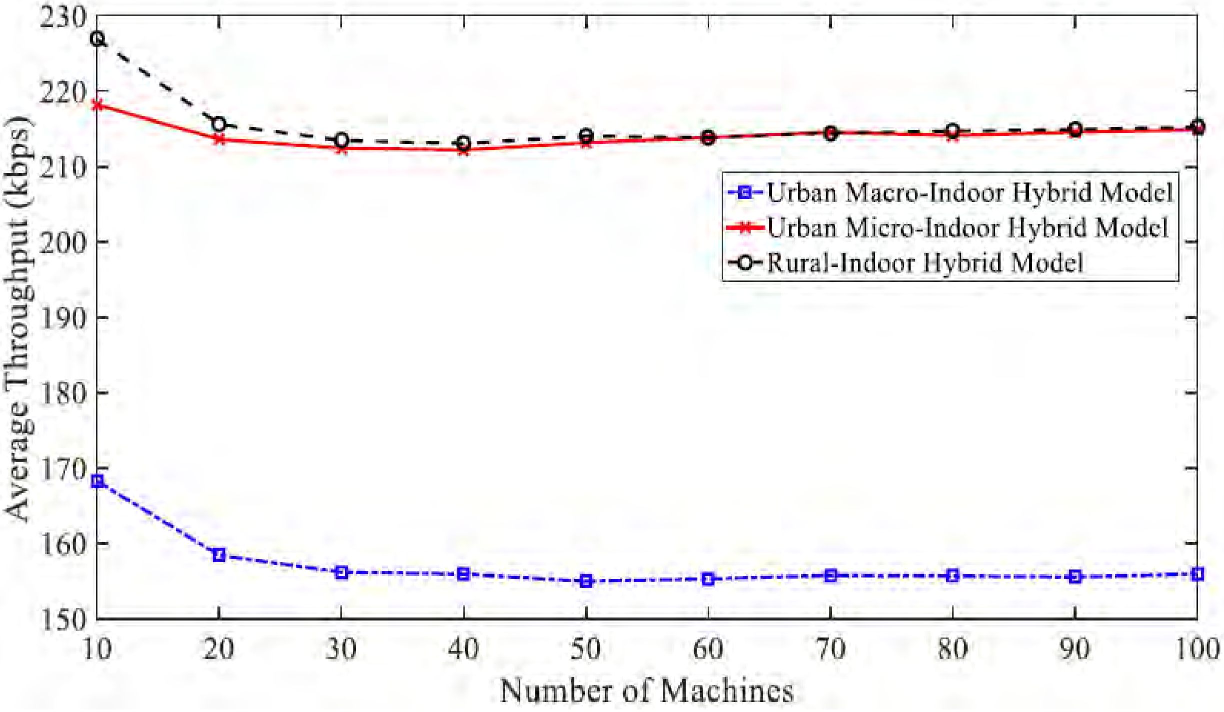

Fig. 4.9: Average throughput of machines for different hybrid channel model scenario in uplink.

Fig. 4.9 compares the uplink throughput with number of machines per cluster for different channel scenarios. Results are provided considering indoor-office scenario in machine-CH link and Rural, Urban micro, Urban macro channel scenario in the CH-BS link. From the simulation plot, it can be observed that the average throughput is higher in rural-indoor hybrid model than urban macro and micro channel model. The reason behind this is the rural areas have lower path loss and shadow fading than urban areas. Consequently, lower path loss produces signals with higher SINR resulting in high throughput.

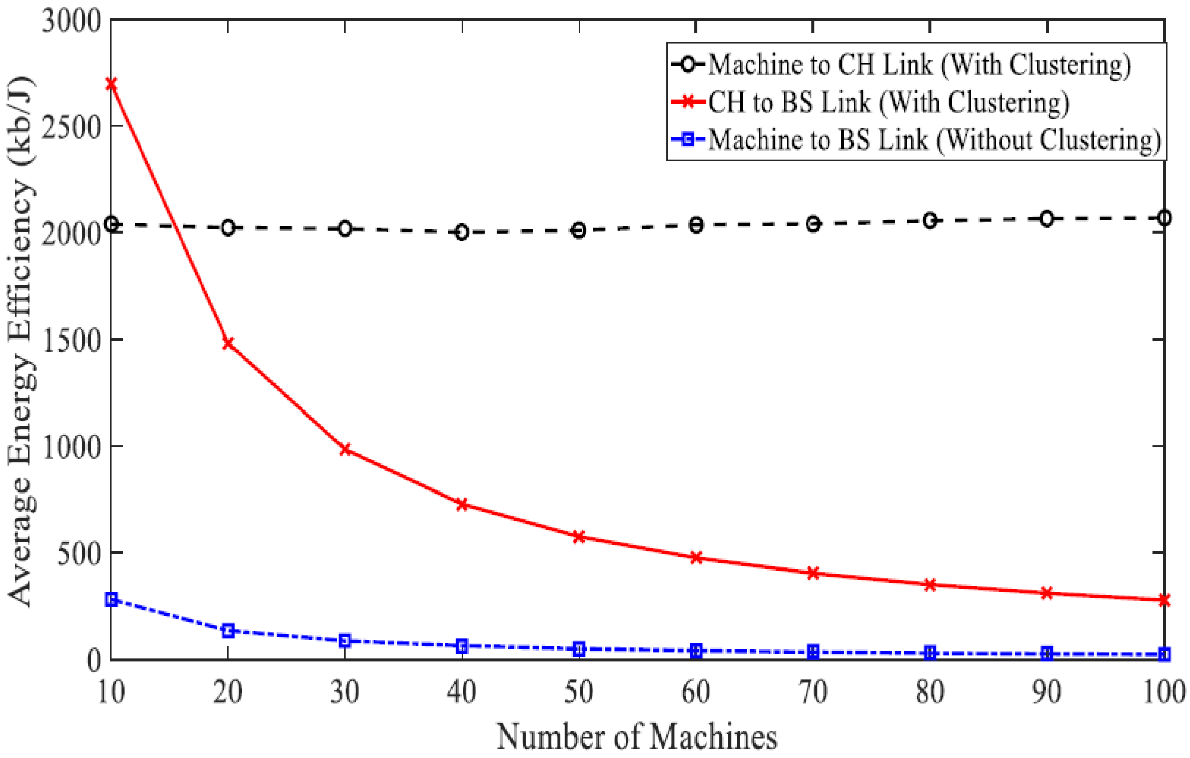

Fig. 4.10: Energy efficiency of machines in uplink with and without clustering.

Fig. 4.10 describes the average energy efficiency of machines in the uplink varying with and without machine clustering system. Simulation results are provided by taking average uplink energy efficiency of various number of machines per cluster in machine-CH, CH-BS and direct machine-BS link. It can be noticed that clustering shows a major impact on the system energy efficiency. In the architecture with clustering, machines achieve significantly better energy efficiency than without clustering. This result explains that when machines communicate directly with BS, data signals have to travel a long distance to BS which causes higher power consumption. On the other hand, in the clustered network energy efficiency in machine-CH link is high because the distance between CH and machines are less which causes low power consumption in data transmission. Additionally, energy efficiency is almost immutable because machines transmit power remains the same as we are using TDMA here. On the contrary, power consumption in CH-BS link increases with an increase in number of machines as the size of total data packet increases. This growth in data size decreases the energy efficiency. However, despite of lower energy efficiency in CH-BS link, the overall energy efficiency in clustered network is greater than without cluster network.

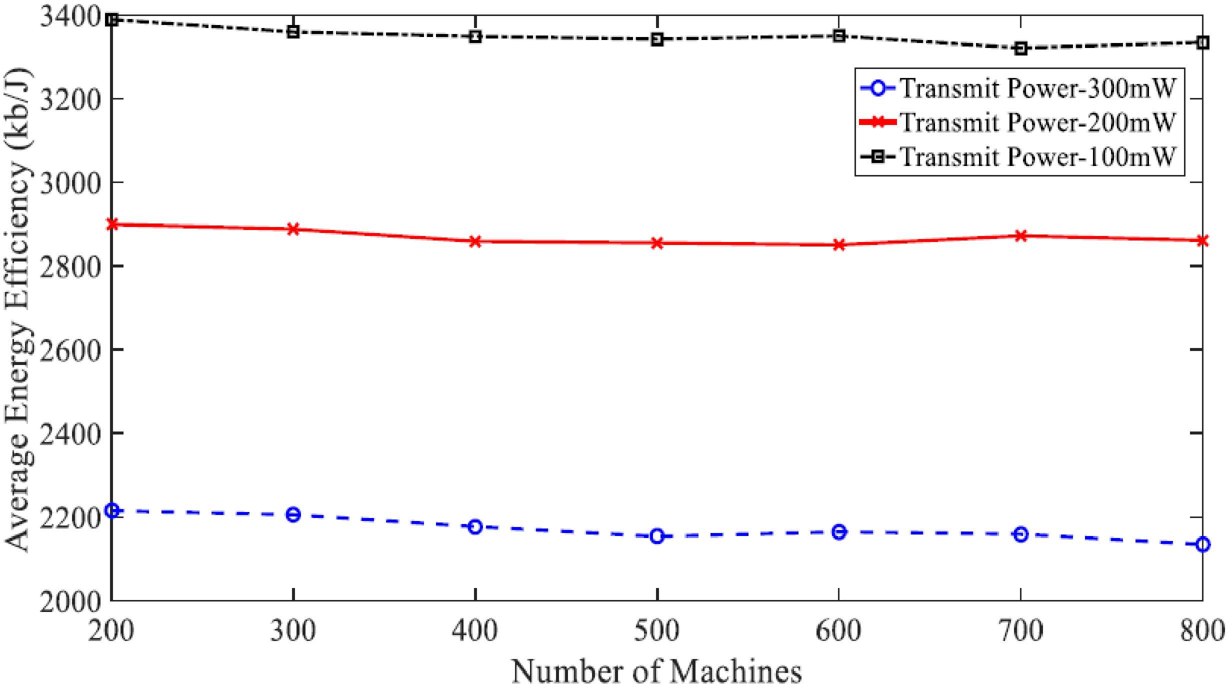

Fig. 4.11: Energy efficiency varying with number of machines.

Similarly, Fig. 4.11 shows the energy efficiency varying with transmit power of machines in the machine-CH link considering NOMA. Simulation results are provided for higher number of machines per cluster and 100, 200, 300 mw transmit power of machines. From Fig. 4.11, it can be identified that the energy efficiency decreases with increase in transmit power as well as the number of machines per cluster. This result explains that increase in number of machines reduce SINR resulting lower channel throughput and also it increases CH transmit power requirement resulting lower energy efficiency. Conversely, lower transmit power of machines reduce power consumption and increase energy efficiency.

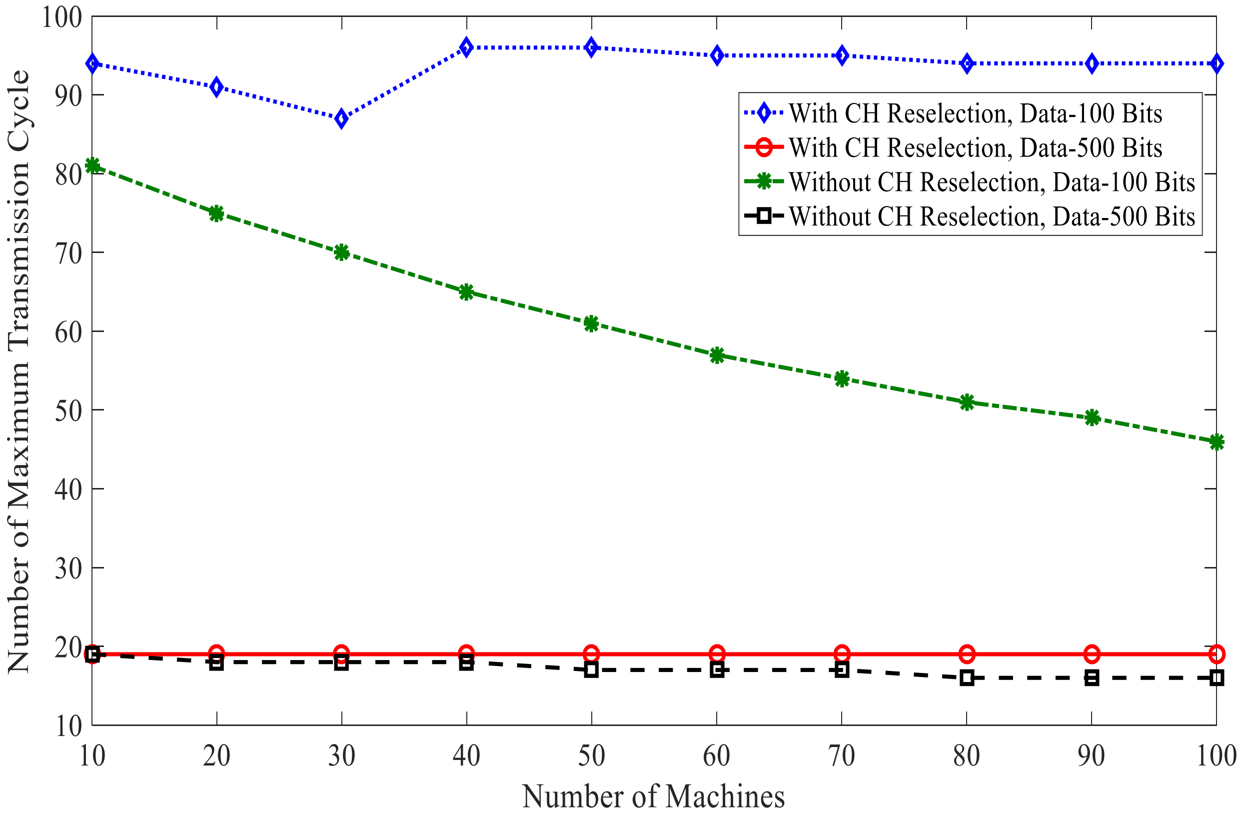

Fig. 4.12: Maximum transmission cycle varying with number of machines.

Fig. 4.12 depicts the number of maximum transmission cycle with the number of machines per cluster. Results are presented considering data sizes of 100 and 500bits. Without CH reselection, number of maximum transmission cycle decreases with the increase in the number of machines per cluster. However for the proposed architecture with CH reselection, machines can run up to higher number of transmission cycle because the energy consumption is balanced between the machines as the duty of CH is rotated among the machines after each transmission cycle. Furthermore, when the data size is 100 bits, network runs more transmission cycle than that of with data size 500 bits. This is because, a small amount of data takes less time and energy to transmit.

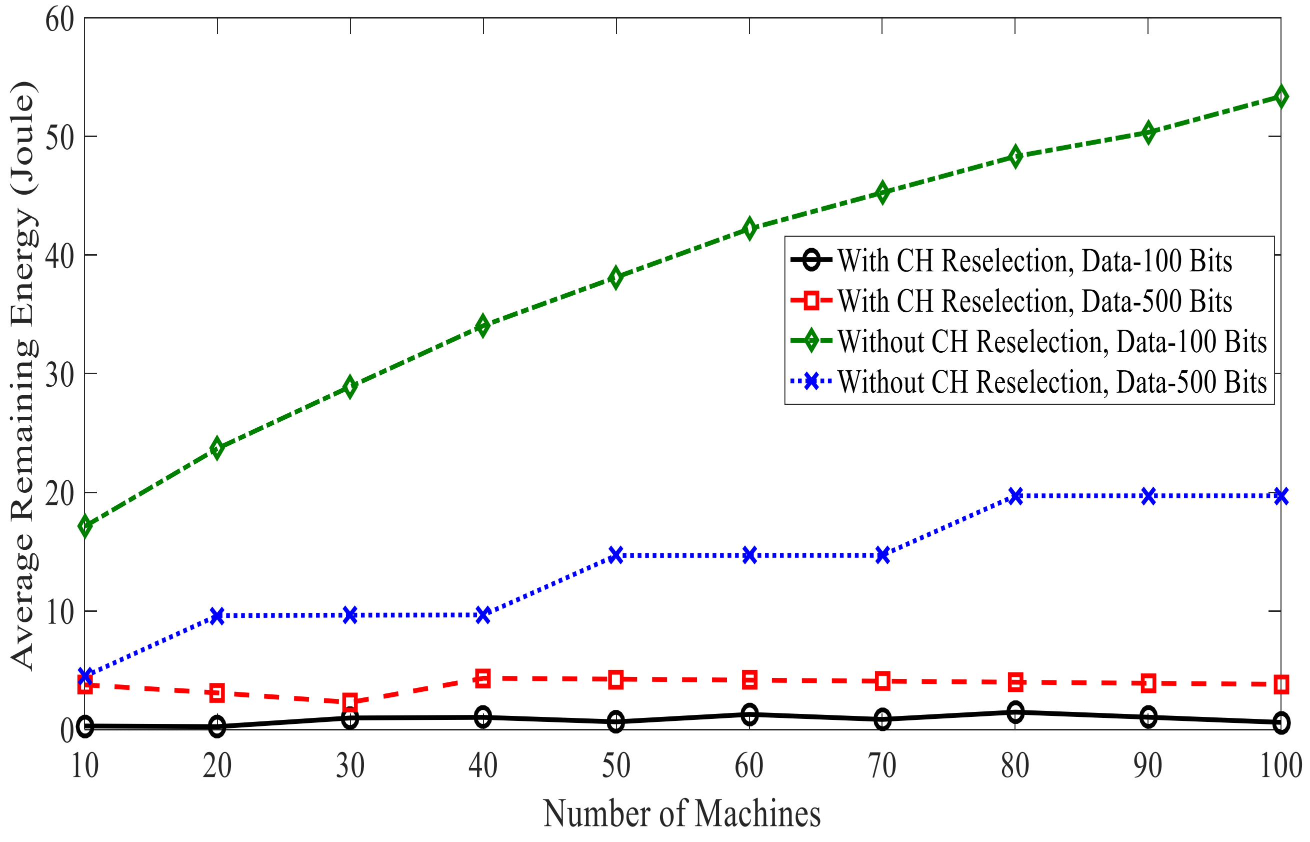

Fig. 4.13: Remaining energy at the end of maximum transmission cycle varying with number of machines.

Fig. 4.13 demonstrates the variation in average remaining energy with the number of machines per cluster for two different data sizes: 100 and 500 bits. Here, the average remaining energy is calculated from the remaining energy in machines at the end of maximum transmission cycle as shown in Fig. 4.12. From the Fig. 4.13, it can be noticed that with CH reselection for 100 bits data, the average remaining energy after the last cycle is mostly lower than that with 500 bits data size. The reason behind this difference is when the data size is small, machines take less amount of time and consumes less energy to transmit. Consequently, with the smaller size of data packet, machines can run a higher number of maximum transmission cycle resulting in a lower remaining energy. On the contrary, when the data size is large, machines run up to a less number of transmission cycle and because of that the average remaining energy stays higher. Whereas, without CH reselection for 100 bits of data packet, the average remaining energy after the last transmission cycle is mostly higher than that with 500 bits data size. This causes due to member machines consume much energy while this large data packet transmission in machine-CH link. Consequently, remaining energy of the machines becomes lower and can run less transmission cycle. Although with 100 bits data packet machines run up to higher number of transmission cycle that that of 500 bits, due of smaller data packet transmission in machine-CH link remaining energy of the machines stay higher.

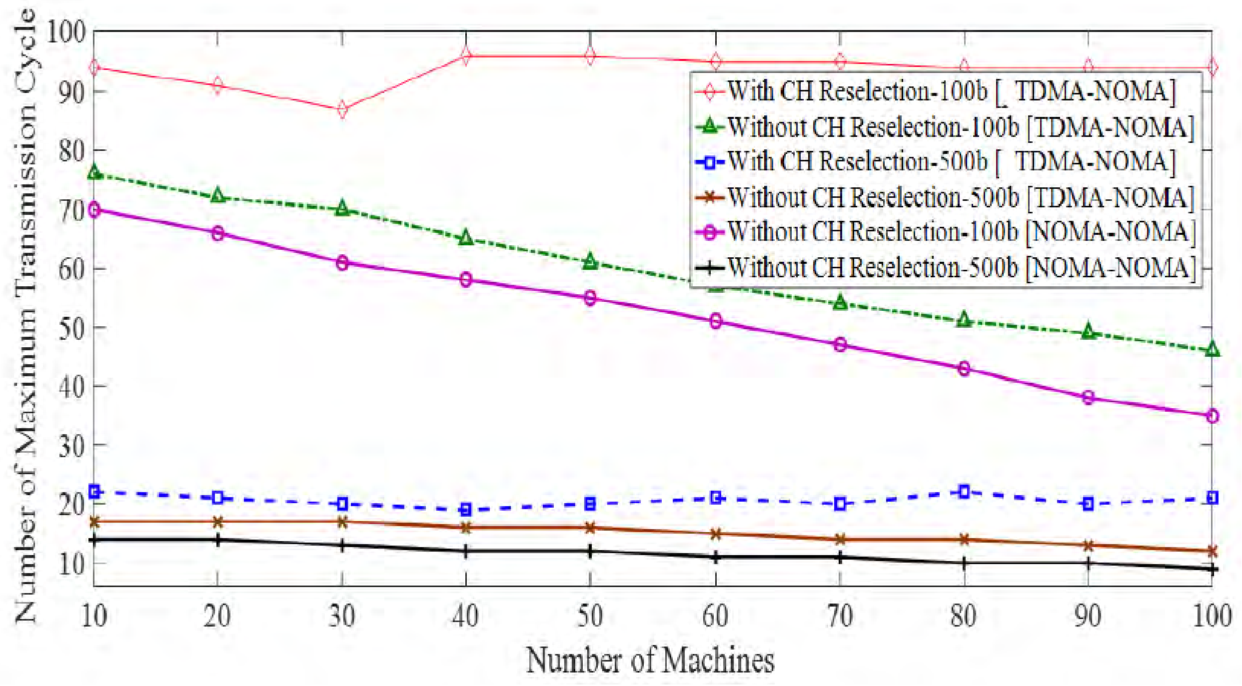

Fig. 4.14: Number of maximum transmission cycle for TDMA-NOMA and NOMA-NOMA.

For the validation of our work, we have compared our work with another research [81] where authors proposed an M2M communication over cellular network using NOMA. Professor Yang et al. has studied the uplink energy minimization using NOMA in machine to user equipment (UE) and UE to BS link. During uplink data transmission, each machine send its designed signal to UE according to NOMA principle. After decoding the data from machines, UE sends the signals to BS simultaneously. In Fig. 4.14, we have implemented the scenario of using NOMA in both link as [81]. It can be observed that, NOMA-NOMA scheme shows degraded performance in maximum transmission cycle than TDMA-NOMA hybrid scheme. As one machine does the transmission for all transmission round, it eventually loses its remaining energy fast and this halts the total communication process. Additionally, using NOMA in machine to UE link increases the signaling interference which also degrades the system throughput as shown in Fig. 4.7. Moreover, authors used an additional machine (UE) as CH, which increases an extra cost and complexity in communication.

4.4 Chapter Summary

The proposed M2M communication architecture over 5G cellular networks incorporated *k*-mean clustering technique and energy based CH reselection method for efficient energy and throughput utilization. Simulation results for considering no channel model demonstrate that the proposed system model is capable of increasing lifetime of machines and reducing communication delay. Through extensive simulations, we have evaluated the system performance considering the newly developed 3D 5G wireless channel models in terms of energy efficiency, life-time of machines and throughput. Impact of system parameters including number of machines, cell radius, transmit power and channel model on system performance are also examined.

Chapter 5

Conclusions and Future works

This chapter summarizes all the overall findings of the research. Possible extensions of this research works are also outlined.

5.1 Conclusions

In this thesis, we have proposed an M2M communication architecture over cellular networks with uplink and downlink transmission using a hybrid TDMA-NOMA based access scheme. To design an energy efficient system, we have applied the *k*-mean clustering algorithm incorporating a CH reselection method. Proposed CH reselection method has been implemented based on the remaining energy in the machines after each transmission cycle. From the simulation results, it has been identified that the proposed CH reselection technique helps to increase the network lifetime by diving the total power consumption between each machine. On the contrary, without CH reselection machines can run only few transmission cycle because of fast energy drain. Furthermore, for the proposed architecture with CH reselection, machines and CH can run up to significantly higher number of transmission cycle because of their proper energy balancing scheme. It has been also illustrated that without CH reselection, number of maximum transmission cycle decreases with the increase in the number of machines per cluster. Moreover, proposed TDMA-NOMA based hybrid multiple access technique have substantially decreased the communication delay than that in TDMA-TDMA based system.

Additionally, we have extended the work by incorporating newly developed 3D 5G wireless channel models. For proper implementation of the proposed architecture, NOMA power coding and SIC scheme has been implemented. Through extensive simulations, we have evaluated the system performance considering the newly developed 3D 5G wireless channel models in terms of energy efficiency, life-time of machines and throughput. Simulation results has demonstrated the average uplink throughput for the proposed architecture with and without machine clustering mechanism. Furthermore, it has been identified that the energy efficiency decreases with increase in transmit power as well as the number of machines per cluster. Results has explained that increase in number of machines reduce SINR resulting lower channel throughput and also it increases CH transmit power requirement resulting lower energy efficiency and vice versa. We have also studied the average throughput for number of machines per cluster altering with different cell radius. Considered different cell area it has been highlighted that machines in a small cell area achieve significantly better throughput performance than that in large cell area due to lower path loss. Overall, from the simulation results, it has been observed that the proposed M2M communication architecture with CH reselection and clustering technique increases the number of transmission cycle, throughput, network lifetime and energy efficiency significantly.

5.2 Future Works

The possible future works for this study shows as follows-

- **Multi-cell Cellular Network:** The proposed M2M communication system architecture has been developed assuming single cell and intra-cell interference network. However, in the proposed M2M communication architecture multi-cell cellular network considering inter-cell interference can be introduced. The result considering inter-cell interference will be able to provide more realistic idea about the traffic scenario of M2M architecture in future cellular network. Therefore, it will be a challenging task to find an effective way to reduce this signaling interference.

- **Advanced Clustering and CH Reselection:** In this research, *k*-mean clustering technique and CH reselection method based on power consumption has been included. To make the system more energy efficient, new clustering system and CH reselection method can be developed. The future research can explore to design efficient clustering for M2M which finds the optimal number of clusters in a cellular so that the overall network energy consumption is minimized. More parameters can be considered for CH reselection after a certain transmission cycle so that the overall network battery life can be maximized.

- **Dynamic TDMA Frame:** Our proposed architecture have introduced TDMA time frames for data transmission between CH and machines. This has increased communication delay in the uplink transmission. This communication delay can be reduced by introducing dynamic TDMA timeslots. Dynamic TDMA timeslots can reduce time consumption by providing different timeslot as per each machine's desired amount of data packet to transmit. Therefore delay as well as power consumption can be minimized.

- **Wake up and Sleep Scheduling:** In the proposed M2M architecture, a smart sleep scheduling technique can be introduced to prolong the network lifetime. As machines in M2M communications are remotely placed, replacing battery is a difficult task. Therefore, duty cycle consideration is of great importance for saving energy and increasing battery life of the machines. Future works can include in designing energy efficient wakeup and sleep scheduling to avoid frequent battery replacing task.

- **Radio Spectrum Partitioning**: Under the same network, allocating radio resources for the M2M traffic will be a difficult task as they generate high signaling interference while transmission. Our simulation result has shown that there remains high signaling interference as multiple machine's use same radio resources. However in future research, radio spectrum partitioning strategy or low complexity resource allocation algorithm can be introduced to improve the signal to noise and interference ratio (SINR) of the data signals of M2M devices.

- **Random Access Scheme:** In the proposed M2M architecture, random access scheme can be introduced for faster data transmission in machine-CH link. To improve the system access capability simultaneously and decrease delay, random access algorithm can be developed replacing TDMA timeslots.

References

[1] M. Tesanovic, P. Bucknell, H. Chebbo and J. Ogunbekun, "Service-domain solutions to radio interference for M2M communications and networking," in *IEEE Globecom Workshops*, Anaheim, US, pp. 1712-1717, December 2012.

[2] A. Aijaz and A. H. Aghvami, "Cognitive Machine-to-Machine Communications for Internet-of-Things: A Protocol Stack Perspective," in *IEEE Internet of Things Journal*, vol. 2, no. 2, pp. 103-112, April 2015.

[3] E. Soltanmohammadi, K. Ghavami and M. Naraghi-Pour, "A Survey of Traffic Issues in Machine-to-Machine Communications Over LTE," in *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 865-884, December 2016.

[4] A. Lo, Y. W. Law and M. Jacobsson, "A cellular-centric service architecture for Machine-to-Machine (M2M) communications," in *IEEE Wireless Communications*, vol. 20, no. 5, pp. 143-151, October 2013.

[5] H. Tian, Y. Xu, K. Xu, J. Jing, and K. Wu, “Energy-efficient user association in heterogeneous networks with M2M/H2H coexistence under QoS guarantees,” in *China Communications*, vol. 12, no. Supplement, pp. 93–103, December 2015.

[6] H. Tian, W. Xie, X. Gan, and Y. Xu, “Hybrid user association for maximizing energy efficiency in heterogeneous networks with human-to human machine-to-machine coexistence,” in *IET Communications*, vol. 10, no. 9, pp. 1035–1043, June 2016.

[7] D. T. Wiriaatmadja and K. W. Choi, "Hybrid Random Access and Data Transmission Protocol for Machine-to-Machine Communications in Cellular Networks," in *IEEE Transactions on Wireless Communications*, vol. 14, no. 1, pp. 33-46, January 2015.

[8] A. Laya, L. Alonso and J. Alonso-Zarate, "Is the Random Access Channel of LTE and LTE-A Suitable for M2M Communications: A Survey of Alternatives," in *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, pp. 4-16, December 2013.

[9] D. Evans, “The Internet of Things - How the Next Evolution of the Internet is Changing Everything,” in *CISCO white Paper*, pp. 1–11, April 2011.

[10] S. N. Swain, R. Thakur and S. R. M. Chebiyyam, "Coverage and Rate Analysis for Facilitating Machine-to-Machine Communication in LTE-A Networks Using Device-to-Device Communication," in *IEEE Transactions on Mobile Computing*, vol. 16, no. 11, pp. 3014-3027, Nov. 2017.

[11] T. Chen, J. Chang and H. Wei, "Dynamic Inter-Channel Resource Allocation for Massive M2M Control Signaling Storm Mitigation," in *IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, QC, pp. 1-5, September 2016.

[12] Z. H. Hussien and Y. Sadi, "Flexible radio resource allocation for machine type communications in 5G cellular networks," *26th Signal Processing and Communications Applications Conference (SIU)*,Izmir, Turkey, pp. 1-4, May 2018.

[13] A. Barki, A. Bouabdallah, S. Gharout and J. Traoré, "M2M Security: Challenges and Solutions," in *IEEE Communications Surveys & Tutorials*, vol. 18, no. 2, pp. 1241-1254, January 2016.

[14] S. C. Jha, A. T. Koc and R. Vannithamby, "Device power saving mechanisms for low cost MTC over LTE networks," in *IEEE International Conference on Communications Workshops (ICC)*, Australia, pp. 412-417, June 2014.

[15] S. Jalali, "M2M solution-Design challenges and considerations," in *IEEE Recent Advances in Intelligent Computational Systems (RAICS)*, Trivandrum, India, pp. 210-214, December 2013.

[16] N. Al-Falahy and O. Y. K. Alani, "Supporting massive M2M traffic in the Internet of Things using millimeter wave 5G network," in *9th Computer Science and Electronic Engineering (CEEC)*, England, pp. 83-88 September 2017.

[17] J. Kim, J. Lee, J. Kim and J. Yun, "M2M Service Platforms: Survey, Issues, and Enabling Technologies," in *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, pp. 61-76, October 2013.

[18] F. Boccardi, R. W. Heath, A. Lozano, T. L. Marzetta and P. Popovski, "Five disruptive technology directions for 5G," in *IEEE Communications Magazine*, vol. 52, no. 2, pp. 74-80, February 2014.

[19] Y. Mehmood, N. Haider, M. Imran, A. Timm-Giel and M. Guizani, "M2M Communications in 5G: State-of-the-Art Architecture, Recent Advances, and Research Challenges," in *IEEE Communications Magazine*, vol. 55, no. 9, pp. 194-201, September 2017.

[20] NTT DOCOMO, "5G radio access: Requirements, concepts and technologies," in *5G White Paper*, Japan, July 2014.

[21] H. Zuo and X. Tao, "Power allocation optimization for uplink non-orthogonal multiple access systems," in *9th International Conference on Wireless Communications and Signal Processing (WCSP)*, China, pp. 1-5, October 2017.

[22] L. Dai, B. Wang, Y. Yuan, S. Han, C. l. I, and Z. Wang, "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends,*" in IEEE Communication Magazine,* vol. 53, no. 9, pp. 74–81, September 2015.

[23] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li and K. Higuchi, "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access," in *IEEE 77th Vehicular Technology Conference (VTC Spring)*, Dresden, Germany, pp. 1-5, June 2013.

[24] V. Pardeshi, T. Wagh and M. Sharma, "Interference Aware Design of NOMA for Large-Scale 5G Networks," in *Fourth International Conference on Computing Communication Control and Automation (ICCUBEA)*, Pune, India, pp. 1-3, August 2018.

[25] D. Zhai, R. Zhang, L. Cai, B. Li and Y. Jiang, "Energy-Efficient User Scheduling and Power Allocation for NOMA-Based Wireless Networks With Massive IoT Devices," in *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1857-1868, June 2018.

[26] A. Benjebbour, A. Li, K. Saito, Y. Saito, Y. Kishiyama and T. Nakamura, "NOMA: From concept to standardization," in *IEEE Conference on Standards for Communications and Networking (CSCN)*, Tokyo, Japan, pp. 18-23, October 2015.

[27] S. M. R. Islam, N. Avazov, O. A. Dobre and K. Kwak, "Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges," in *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721-742, October 2016.

[28] S. Hamdoun, A. Rachedi, H. Tembine and Y. Ghamri-Doudane, "Efficient transmission strategy selection algorithm for M2M communications: An evolutionary game approach," in *IEEE 15th International Symposium on Network Computing and Applications (NCA)*, Cambridge, MA, pp. 286-293, November 2016.

[29] M. Chen, “Towards smart city: M2m communications with software agent intelligence,” in *Multimedia Tools and Applications*, vol. 67, no. 1, pp. 167–178, 2013.

[30] Y. Liao and L. Song, "Computing resource constraint in wireless M2M communications," in *IEEE 17th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Edinburgh, UK, pp. 1-6, July 2016.

[31] Technical report “Machine-to-Machine Communications (M2M), Functional Architecture,” in *ETSI TS 102 690*, vol. 2.1.1, October 2013.

[32] M. J. Booysen, S. Zeadally, and G.-J. van Rooyen, “Survey of Media Access Control Protocols for Vehicular Ad Hoc Networks,” in *IET Communication*, vol. 5, no. 11, pp. 1619–3, August 2011.

[33] ETSI-M2M. Machine-to-Machine communications (M2M); Functional architecture, Technical Specification, TS 102 690, 2011. Available from:

http://www.etsi.org/deliver/etsi_ts/102600_102699/102690/01.02.01_60/ts_102690v010201p.pdf. [Accessed May 31, 2019]

[34] Technical Report, “System improvements for machine-type communications,” in 3GPP 23.888, vol. 1.3.0, June 2011.

[35] Technical Report, ITU: F. Group, “ITU-T FG M2M,” in ITU, vol. 0, 2014.

[36] A. Daj, C. Samoilă and D. Ursuţiu, "Digital marketing and regulatory challenges of Machine-to-Machine (M2M) Communications," in *9th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, Bilbao, Spain, pp. 1-5, July 2012.

[37] M. Jaber, N. Kouzayha, Z. Dawy and A. Kayssi, "On cellular network planning and operation with M2M signalling and security considerations," in *IEEE International Conference on Communications Workshops (ICC)*, Sydney, Australia, pp. 429-434, June 2014.

[38] H. Shahwani, S. Muneer and J. Shin, "An energy efficient clustering technique in M2M based on affinity propagation," in *International Conference on Emerging Technologies (ICET)*, Pakistan, pp. 1-4, October 2016.

[39] S. Singh and K. Huang, "A robust M2M Gateway for effective integration of capillary and 3GPP networks," in *Fifth IEEE International Conference on Advanced Telecommunication Systems and Networks (ANTS)*, Bangalore, India, pp. 1-3, December 2011.

[40] I. Park, D. Kim and D. Har, "MAC Achieving Low Latency and Energy Efficiency in Hierarchical M2M Networks With Clustered Nodes," in *IEEE Sensors Journal*, vol. 15, no. 3, pp. 1657-1661, March 2015.

[41] F. Ghavimi and H. Chen, "M2M Communications in 3GPP LTE/LTE-A Networks: Architectures, Service Requirements, Challenges, and Applications," in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 2, pp. 525-549, October 2014.

[42] I. Bang, K. S. Ko and D. K. Sung, "A user-pairing based resource allocation scheme for a large number of devices in M2M communications," in *IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, London, UK, pp. 1554-1558, September 2013.

[43] M. Naeem *et al.*, "Distributed Gateway Selection for M2M Communication in Cognitive 5G Networks," in *IEEE Network*, vol. 31, no. 6, pp. 94-100, December 2017.

[44] DU Jiang, CHAO ShiWei*,* "A Study of Information Security for M2M of IoT*",* in *3rd International Conference on Advanced Computer Theory and Engineering*, Chengdu, China, pp.-576-579, August 2010.

[45] A. Imani, A. Keshavarz-Haddad, M. Eslami and J. Haghighat, "Security Challenges and Attacks in M2M Communications," in *9th International Symposium on Telecommunications (IST)*, Tehran, Iran, pp. 264-269, December 2018.

[46] M. Hossein Ahmadzadegan and T. Fabritius, "A multi-purpose triangular framework for M2M communication security," in *World Congress on Computer Applications and Information Systems (WCCAIS)*, Tunisia, pp. 1-5, January 2014.

[47] S. Chen, R. Ma, H. Chen, H. Zhang, W. Meng and J. Liu, "Machine-to-Machine Communications in Ultra-Dense Networks—A Survey," in *IEEE Communications Surveys & Tutorials*, vol. 19, no. 3, pp. 1478-1503, March 2017.

[48] Y. Lin, S. Li, P. Duo and Y. Xu, "A tree topology power allocation algorithm for non-orthogonal multiple access system in 5G system," in *13th International Conference on Natural Computation, Fuzzy Systems.*

[49] M. Zeng, A. Yadav, O. A. Dobre and H. V. Poor, "Energy-Efficient Power Allocation for MIMO-NOMA with Multiple Users in a Cluster," in *IEEE Access*, vol. 6, pp. 5170-5181, February 2018.

[50] S. Timotheou and I. Krikidis, "Fairness for Non-Orthogonal Multiple Access in 5G Systems," in *IEEE Signal Processing Letters*, vol. 22, no. 10, pp. 1647-1651, October 2015.

[51] F. Liu and M. Petrova, "Dynamic Power Allocation for Downlink Multi-Carrier NOMA Systems," in *IEEE Communications Letters*, vol. 22, no. 9, pp. 1930-1933, September 2018.

[52] J. Datta and H. Lin, "Detection of uplink NOMA systems using joint SIC and cyclic FRESH filtering," in *27th Wireless and Optical Communication Conference (WOCC)*, Hualien, Taiwan, pp. 1-4, May 2018.

[53] Z. Ding Yuanwei Liu, Jinho Choi, Qi Sun, Maged Elkashlan, "Application of Non-Orthogonal Multiple Access in LTE and 5G Networks," in *IEEE Communications Magazine*, vol. 55, no. 2, pp. 185-191, February 2017.

[54] P. D. Diamantoulakis, K. N. Pappi, Z. Ding and G. K. Karagiannidis, "Wireless-Powered Communications With Non-Orthogonal Multiple Access," in *IEEE Transactions on Wireless Communications*, vol. 15, no. 12, pp. 8422-8436, December 2016.

[55] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan and V. K. Bhargava, "A Survey on Non-Orthogonal Multiple Access for 5G Networks: Research Challenges and Future Trends," in *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2181-2195, October 2017.

[56] H. Zheng, S. Hou, H. Li, Z. Song and Y. Hao, "Power Allocation and User Clustering for Uplink MC-NOMA in D2D Underlaid Cellular Networks," in *IEEE Wireless Communications Letters*, vol. 7, no. 6, pp. 1030-1033, December 2018.

[57] NTT Docomo, “Requirements, candidate solutions and technology roadmap for LTE Rel-12 onward,” in *3GPP RWS-120010*, June 2012.

[58] A. Dalili Shoaei, M. Derakhshani and T. Le-Ngoc, "A NOMA-Enhanced Reconfigurable Access Scheme With Device Pairing for M2M Networks," in *IEEE Access*, vol. 7, pp. 32266-32275, March 2019.

[59] Z. Ding, L. Dai, R. Schober, H. V. Poor, "NOMA meets finite resolution analog beamforming in massive MIMO and millimeter-wave networks", in *IEEE Communication Letters*, vol. 21, no. 8, pp. 1879-1882, August 2017.

[60] T. Lv, Y. Ma, J. Zeng and P. T. Mathiopoulos, "Millimeter-Wave NOMA Transmission in Cellular M2M Communications for Internet of Things," in *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1989-2000, June 2018.

[61] H. S. Dhillon, H. Huang, H. Viswanathan and R. A. Valenzuela, "Fundamentals of Throughput Maximization With Random Arrivals for M2M Communications," in *IEEE Transactions on Communications*, vol. 62, no. 11, pp. 4094-4109, November 2014.

[62] Z. Yang, Y. Pan, W. Xu, R. Guan, Y. Wang, M. Chen, “Energy efficient resource allocation for machine-to-machine communications with NOMA and energy harvesting,” in *INFOCOM WKSHPS*, Atlanta, GA, USA, pp. 1-6, May 2017.

[63] H. S. Dhillon, H. Huang, H. Viswanathan and R. A. Valenzuela, "Fundamentals of Throughput Maximization With Random Arrivals for M2M Communications," in *IEEE Transactions on Communications*, vol. 62, no. 11, pp. 4094-4109, November 2014.

[64] T. A. Zewde and M. C. Gursoy, "NOMA-Based Energy-Efficient Wireless Powered Communications in 5G Systems," in *IEEE 86th Vehicular Technology Conference (VTC-Fall)*, Canada, pp. 1-5, September 2017.

[65] P. Zhang and G. Miao, "Energy-Efficient Clustering Design for M2M Communications," in *IEEE Global Conference on Signal and Information Processing (GlobalSIP*), Atlanta, GA, USA, pp. 163-167, December 2014.

[66] Y. Da Tsai, C. Y. Song, and H. Y. Hsieh, “Joint optimization of clustering and scheduling for machine-to-machine communications in cellular wireless networks,” in *IEEE Vehicular Technology Conference*, vol. 2015, Glasgow, UK, pp. 1–5, May 2015.

[67] I. Park, D. Kim, “MAC Achieving Low Latency and Energy Efficiency in Hierarchical M2M Networks With Clustered Nodes,” in *IEEE Sensors Journal*, vol. 15, no. 3, pp. 1657–1661, March 2015.

[68] D. Sisodia, “Clustering Techniques : A Brief Survey of Different Clustering Algorithms,” in *International Journal of Latest Trends in Engineering and Technology (IJLTET),* vol. 1, no. 3, pp. 82–87, September 2012.

[69] G. Kılıç and T. Girici, "Clustering in cellular M2M communications," in *22nd Signal Processing and Communications Applications Conference (SIU)*, Turkey, pp. 1662-1665, April 2014.

[70] S. Wang, H. Su, H. Hsieh, S. Yeh and M. Ho, "Random access design for clustered wireless machine to machine networks," in *First International Black Sea Conference on Communications and Networking (BlackSeaCom)*, Batumi, Georgia, pp. 107-111, July 2013.

[71] P.-N. Tan, M. Steinbach, and V. Kumar, “Cluster Analysis: Basic Concepts and Algorithms,” in *Introduction to Data Mining*, chapter 8, pp. 1-82, 2005.

[72] S. Na, L. Xumin and G. Yong, "Research on k-means Clustering Algorithm: An Improved k-means Clustering Algorithm," in *Third International Symposium on Intelligent Information.*

[73] N. Ganganath, C. Cheng and C. K. Tse, "Data Clustering with Cluster Size Constraints Using a Modified K-Means Algorithm," in *International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery*, Shanghai, China, pp. 158-161, October 2014.

[74] J. Qi, Y. Yu, L. Wang and J. Liu, "K*-Means: An Effective and Efficient K-Means Clustering Algorithm,"*IEEE International Conferences on Big Data and Cloud Computing (BDCloud), Social Computing and Networking (SocialCom), Sustainable Computing and*

Communications (SustainCom) (BDCloud-SocialCom-SustainCom), Georgia, US, pp. 242-249, October 2016.

[75] J. Hong, M. Park and N. Okazaki, "SGM: A Subgroup Management Scheme Using K-Means Clustering in M2M Systems," *19th International Conference on Network-Based Information Systems (NBiS)*, Czech Republic, pp. 146-151, September 2016.

[76] J. N. Al-Karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: a survey," *IEEE Wireless Communication*, vol. 11, no. 6, pp. 6-28, December 2004.

[77] M. S. Al-kahtani, “ECSM : Energy Efficient Clustering Scheme for Mobile Communication Networks,” in *CS & IT-CSCP*, pp. 1–11, 2014.

[78] K. V. Deshpande and A. Rajesh, "Design of an improved energy efficient clustering in M2M communication," *International Conference on Circuits, Power and Computing Technologies,* India, pp. 1-6, March 2015.

[79] Technical Report, “3gpp tr 38.901,” in *3GPP TR 38.901*, vol. 14.3.0, December, 2017.

[80] A. B. Rozario and M. F. Hossain, "An Architecture for M2M Communications Over Cellular Networks Using Clustering and Hybrid TDMA-NOMA," in *6th International Conference on Information and Communication Technology (ICoICT)*, Bandung, Indonesia, pp. 18-23, May 2018.

[81] Z. Yang, W. Xu, H. Xu, J. Shi and M. Chen, "Energy Efficient Non-Orthogonal Multiple Access for Machine-to-Machine Communications," in *IEEE Communications Letters*, vol. 21, no. 4, pp. 817-820, April 2017.