Joint user selection and BS (Base Station) assignment strategy in Smart grid.

By

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In The name of Allah the most Beneficent and the most Merciful

DEDICATION

Dedicated to my family who has always been a source of motivation for me and also to my supervisor Col Dr Adnan Ahmed Khan for being forthcoming and helping in fulfillment of this research work.

ABSTRACT

Smart grid is an emerging technology that is of worth importance in efficient utilization of power. It is that communication and information technology that converts the typical grid systems into smarter one. There is a two way data flow between the supplier and the consumer that uses appropriate communication technology for that flow of information. So, this communication technology plays a pivotal role in these upgraded grid systems. In order to improve the performance of smart grids, one have select suitable network for communication and then optimize that network using different optimization techniques.

Wireless communication network is the best option for transference of information in smart grids due to their reliability, security, maturity, more coverage area as well as ease of deployment. Our focus is to optimize this selected cellular network to improve the overall performance of the network.

The main objective of this work is to find the best possible combination of user and BS (Base station) that in turn maximizes the overall throughput of the network for better efficiency of the network. There exists some conventional techniques for user and BS assignment which uses max-SINR rule. According to this techniques, the resources to each user are allocated on the basis of max-SINR which is not suitable for heterogenous network where pico/femto cells are deployed under macro BSs. Optimization of the network is done using heuristic as well as optimal algorithms. Heuristic approach always gives better results as compared to optimal results. Computational complexity is also decreased as compared to existing work.

CERTIFICATE

It is to certify that final copy of thesis written by **Mr Muhammad Fawad Khan** of Military College of Signals has been evaluated by me, found complete in all respect as per the specified format of NUST Statutes / Regulations, is free of plagiarism, errors and mistakes.

Dated: _____ _____

Col Dr Adnan Ahmed Khan

DECLARATION

No content of work presented in this thesis has been submitted in support of another award of qualification or degree either in this institution or anywhere else.

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Chapter # 1

1. Introduction

1.1 Conventional grid vs smart grid:

The typical power grid had served us for a long time and gave satisfactory performance for decades from the time of deployment. As it is unidirectional flow of electricity with some old traditional techniques of power distribution that are not fulfilling the present and the future demands of mankind. There is no communication or data flow between the distributor and the consumer in conventional grid and reliability factor is decreasing day by day that makes them obsolete and thus demands a new and a better system of electricity distribution[1]. A system that is smarter and more efficient than the conventional one. Researchers came up with the solution and termed it as smart grid. Smart grid is basically the automated electrical grid system that overcome the challenges of reliability, security and inefficient utilization of energy faced by the conventional electrical grids. This automated grid is enabled with state of the art information and communication technologies that makes it more efficient [2-3].

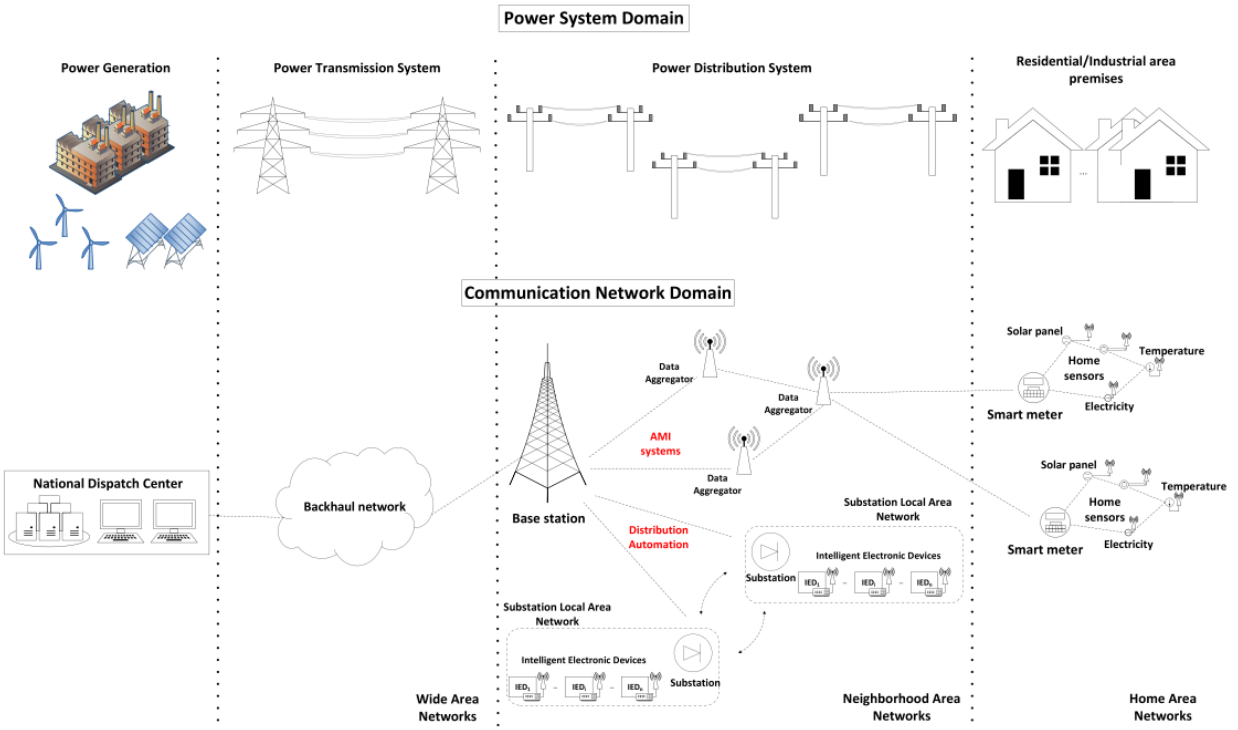

Figure 1. 1: Conventional vs smart grid

1.2 Need For Smart Grid:

The growing demand of electricity consumption all over the world forced the researchers for a new mega infrastructure for power distribution. The number of outages are increasing due to change in weather conditions. All these changes have a direct bad impact on the aged infrastructure. Dealing with these severe outages that are increasing every few years are getting more difficult and inefficient with time. In fact, it is predicted that the world demand of electricity consumption will be increased three times more by 2050. In addition to all this, the existing infrastructure reduces its energy intensity by 2% every year[4]. Considering all these points world needs an efficient, reliable and secure power generation and distribution mechanism.

Risks of massive blackouts are involved in not implementing a control and updated infrastructure for electric grids where consumption is increasing continuously. Sometimes these blackouts affect millions of users which in turn bring huge losses to the economy of the countries. We also need to control the increasing demand of power from consumer side in order to manage and maintain a balance between consumption and generation.

1.2.1 Reliability:

There are several weaknesses regarding outage management system in old grid systems which is directly related to the reliability of the system. Current centralized grid system is more vulnerable regarding natural disasters or attacks as in such situations it requires long time to reconstruct that huge infrastructure. While in intelligent grid like smart grid, appropriate communication is carried out to report the outage to the monitoring center and thus redirected the power to that place.

1.2.2 Renewable Energy resources:

Power generation from renewable energy resources like wind, solar, tidal, nuclear and geothermal is becoming an important concern in order to get rid of energy crises by producing cheap electricity. Though these resources reduces the cost but power generated from renewable energy resources are intermittent and we need and automated grid systems that can handle both intermittent and distributed power sources.

1.3 Heart of Smart grid:

There is a two way information exchange in smart grid network which helps in improving the reliability, sustainability and effectiveness of the grid. The communication between power distributor and the consumer plays a pivotal role in smart grids. This communication network is actually the backbone or heart of smart grid systems that converts the typical grid to smarter one. It helps to collect information from the

consumer side and transfers it to the generator and power distributor to make the energy utilization more and more efficient. For example if a consumer gets the power price per unit and he is well aware of peak hours, then he can control over monthly bills by reducing the consumption of electricity at peak hours. Similarly the supplier can switch to solar energy at day time, monitors continuously the overall consumption, have all substations and consumers statistics, get alerts of any outage well in time and make necessary actions accordingly. All this become possible due the automated grid and this automated grid is capable of doing all these preventive and effective actions due to the controlled communication network which is the backbone of smart grid network. So whenever we talk about smart grid network, the main point of concern in the network will obviously be the information and communication technology.

Figure 1.2 shows different stake holders of smart grid network. If we remove the block of information and communication technology from the figure, the rest is the setup of existing grid systems that generates and simply transmits the power to the consumer. The scenario become totally change by simply adding one entity that is communication technology. Among all these major stake holders, notice that communication network is the one who links up all the other blocks to each other and makes a strong and the most effective part of the network.

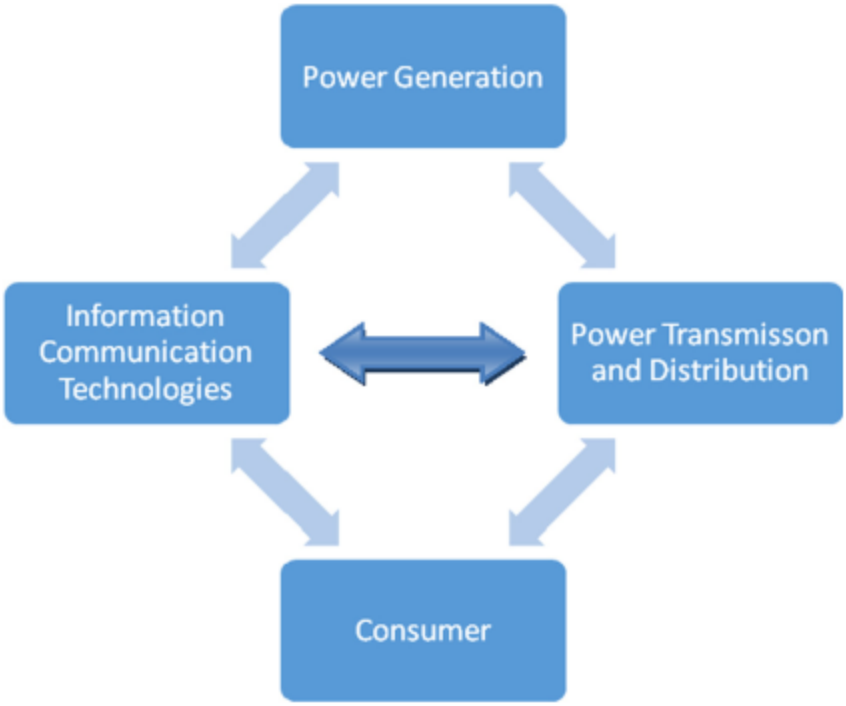

Figure 1. 2: Major stake holders of smart grid

1.4 Communication and Information exchange:

Cellular networks were initially designed for *voice* applications. However, with the introduction of data service with ubiquitous connectivity to the Internet, cellular network operators are facing an overwhelming growth of data traffic demands mainly fueled by the rapid development of high-end mobile devices including smart-phones and tablets. A large portion of this data is expected to be mobile video that has a much larger rate requirement than voice or web-browsing. 65% increase in mobile traffic demand between the years 2013 and 2014. It also forecasts a 10 folds increase in mobile traffic between the years 2013 and 2019. Different generations of wireless cellular networks (3G, LTE, 4G etc.) have tried to keep up with this ever-increasing demand. The next generation of these technologies, often referred to as the fifth generation (5G), is expected to support even more traffic.

Unlike in wired networks, capacity expansion of wireless networks is not easy. Adding more copper approach does not work for wireless networks, mainly due to the limited availability of wireless spectrum. Improving the utilization of the spectrum by employing smart radio technologies like *cognitive radio* has been the subject of many recent studies. Improving the spectral efficiency of a point-to-point link has always been a major focus in wireless research. Important innovations in physical layer technologies have made wireless broadband access to Internet feasible. However, as the spectral efficiency of a point-to-point link is quickly approaching theoretical limits, this line of thinking alone is not going to be sufficient. Obviously, if more spectrum are being made available for wireless network operation, that would bring many-fold increase in network capacity. Due to some recent policy-level decisions, more spectrum is indeed available especially at higher frequencies (e.g., mmWave bands). However, communication technologies at these bands are still far from mature, and are not expected to be main-stream any time soon.

In the recent years, solutions based on topological and architectural innovations have gathered a lot of interest, both in the industry and the academia as well. The main idea involves *network densification* in the form of *Heterogeneous Cellular Networks*.

1.5 Heterogeneous Networks:

Heterogeneous Networks (HetNets) involve an arrangement of low-power base stations (BSs) overlaying the current full scale cell framework. These low power BSs shape little cells inside the full scale cell inclusion region of large scale base stations (MBS). These BSs are basically alluded to as small cells (SC). These SCs are regularly associated with the center by means of some backhaul framework. Pico base stations (PBS) are operator-deployed small BSs connected to the core via wired backhaul links. Femto

base stations (FBS) are much smaller in form-factor and coverage, and are often used for indoor coverage with inexpensive backhaul links. Relay Nodes (RNs) are small cells with wireless backhaul links to the macro cell. An example of a HetNet with a mix of PBSs and RNs is depicted in Fig. 1.2.

1.6 Small cells with wired backhaul links:

Talking about the wired scenario that is the most common one in which small cells (SCs) are connected to the macro BS (MBS) using a wired backhaul link. It is further categorized into three types, access link (AL) that connects SCs and user terminal, the direct link (DL) that is responsible for the connection between MBS and user terminal and a wired backhaul link for connecting MBS and SCs. The first two types lies under the category of *user links*. If the backhaul links are sufficiently provisioned, the performance of such HetNet would depend on the radio resource management (RRM) algorithms and techniques used in the user links. It is historically the case that the capacity bottlenecks are in the wireless access end, and hence backhauling is often assumed to be ideal. In the future ultra-dense HetNets, this assumption might need to be revisited, meaning that backhaul link considerations are to be incorporated.

1.7 Small cells with wireless backhaul links:

Setting only wired connection for backhaul links does not always work in a better way. Deploying wireless relay nodes instead of rigid wired setup have more flexibility in many circumstances. HetNets with relay nodes (RN) are considered as a great enhancement in order to improve the MBS capacity and coverage area, and thus termed as relay enhanced cellular (REC) network. This thing increases the communication between UE and MBS using famous decoding and forwarding the data packets. These relay nodes (RN's) are to be considered as a separate identity as small cell BSs with wireless backhaul link operating within the set of bands similar to user links. So, there is no additional frequency band is available for operating the backhaul links. Such a situation

is referred as user-band relay scenario. Dissimilar with wired link, the wireless backhaul links are in competition with the user link in getting the radio resources (time, frequency and transmit power). There exists numerous configurations that exists and different depending on the node capabilities including directivity of air interfaces, number of air interfaces as well as the procedure of allocation of channel resources to various links.

Another solution for wireless backhaul case also exits in which backhaul link is given a separate band from entire available spectrum. This is termed as dedicated-band relay scenario. But there is a constraint of spectrum scarcity. Wireless industry is growing ata tremendous rate and spectrum scarcity is a consistent challenge faced by the wireless networks. Recently, researchers are going for some unused portion of spectrum i.e mmWave bands. But the challenge is the designing of hand held equipment on this specific range of spectrum. Instead of this, utilization of this unused portion for static backhaul link seems to be a better solution for overwhelming scarcity problems of frequency spectrum.

1.8 Challenges

1.8.1 Diverse deployment scenarios:

The above discussion is the evident that HetNets comprises different categories of backhaul links with various limitations as well as different deployment scenarios, band and air interface technologies and diverse topologies. Keeping the eye of an engineer, these scenarios have much importance to study under same framework. By doing so would enable the path of comparative study among different types of deployment choices under unified framework model.

1.8.2 Different network processes and their complex interplay:

This type of splitted architecture in which a new topology is introduced having small cells under high power macro cells leads towards many challenging situations. Some of

the main challenges are resource allocation, user association and user scheduling and transmission coordination that are collectively linked with interference management and overall throughput of the network. These different deployment scenarios are of worth when considering the cellular networks and must be analyzed critically.

1.8.3 Resource allocation:

It means allocating the resources to identities of wireless network like network nodes (BSs) and users. Taking OFDM case of wireless network, subchannels are the main example of such resources. In a specific resource allocation scheme, it is determined by the mechanism of resource allocation that how these channels/ resources are allocated to different entities of wireless network. Resource allocation in homogenous network is often very simple as it includes allocation among nodes of similar load and coverage. For example, equal number of channel resources can be allocated to different BSs by simply using a reuse pattern of channel allocation. By using this approach not only simplifies the allocation of resources, but also offers a certain level of interference guarantees, as the influence of interference among the BSs is rather symmetric. In heterogeneous networks, multiple deployed nodes have different load and coverage area. The unequal power of MBS and the small cells makes the interference asymmetric which in turn makes resource allocation scheme more complex and challenging.

In wired deployment case of small cells, resource allocation includes assignment of channel resources to the direct links and the access links. Taking three types of resource allocation schemes: *Orthogonal deployment* (OD), *Co-channel deployment* (CCD) and *Partially shared deployment* (PSD). In Co-channel deployment, the radio resource that are available will be used by all the BSs within a given macro coverage. In Orthogonal deployment, channels are actually divided between the SCs (small cells) and the MBS in order to kept the interference at a reasonable level. In

Partially shared deployment, MBS is allowed to transmit on the channels available to the SCs, albeit at a lower power. It is necessary to tune some of the resource allocation schemes. By selecting an appropriate of optimal choice of these parameters would result in good performance, but it is not trivial. Considering some of the parameters as resource allocation variables then a good resource allocation algorithm would aim at finding good values for these variables. These algorithms are very helpful in making decisions regarding the optimal allocation of resources leading towards betterment in the performance of the network. These schemes and algorithms specifies the division of channels among the MBS and SCs. A higher level resource allocation scheme or algorithm must be used in order to determine what channels are available in a given macro BS.

An additional type of backhaul link is introduced by the case of relay deployment. The addition yields more distinct ways in which we could allocate resources and it is often very difficult to make comparison and understand which ones are better than the others.

1.8.4 User scheduling and transmission coordination

User scheduling (US) is done by each BS on the allocated channels by resource allocation algorithm, to meet some throughput objective (e.g., proportional fairness (PF) in homogenous networks. In that case, a BS schedules its users independently of the other BSs. However, this per-BS (also called local) user scheduling model needs to be revisited in the HetNet context. User scheduling is seen as an important network process that can be used to manage interference among the BSs. This interference management can be done by coordinating the transmissions of the BSs. This *transmission coordination* (TC) can be achieved by scheduling the BSs in time together with power control at each BS, which is very complicated. Another type of transmission coordination is available in which a BS can either be transmitting with the maximum

available power or not transmitting is called the ON-OFF TC (Transmission Coordination) which is considered by 3GPP as a suitable mechanism for LTE-A networks. If transmission coordination among BSs is possible, independent local user schedulings are not optimal from the network performance point of view. In this case, user scheduling decision might need to be taken across different BSs jointly. So, TC (Transmission Coordination) is tightly coupled with user scheduling yields multiple BSs mandates a global (i.e., across multiple BSs) optimization mechanism.

Even without transmission coordination, there is a need to look at user scheduling as a global process for the scenarios where the backhaul links have capacity limitations. This includes the wired as well as the relay deployment scenarios. In these cases, it can be shown that user scheduling decision at a BS impacts another BS, and thus a global approach to user scheduling can yield the best performance (a local approach could yield infeasible solutions if not performed properly). However, a global approach to user scheduling leads to high complexity. The trade-off between local user scheduling and globally optimized user scheduling is not well understood.

1.8.5 User association

In homogeneous networks, cells are usually non-overlapping (except at the cell-edge) and thus a user associates to the BS that offers the best Signal to Noise-plus-Interference Ratio (SINR) value. However, in a HetNet context, such an approach does not work well. Since the MBS transmits at a higher power, the received SINR from the MBS is usually much higher than the SINR from the low power BSs, thereby making more users associate to the MBS. This in effect nullifies the vision of the HetNet deployment. It is thus important to revisit user association in the HetNet context.

1.9 Interplay of network processes

Each of the above-mentioned network processes can be fine-tuned to yield good network performances. But, it is often the case that one process impacts the other, and

the interplay is usually complex. Understanding them, and taking the right deployment configuration is important to realize the *HetNet potential.*

Chapter # 2

2. Communication Technologies for Smart grid

2.1 Background:

Smart grid has a wide area of applications and they rely on communication technologies. Generally wireless communication is preferred as compared to wired solutions due to its lower cost, flexibility, quick deployment and greater access [5]. In wireless communication technology there are several technologies that are suggested for smart grid applications and elaborated the challenges associated with them in [6]. The components of smart grid includes smart meters, sensors, proper data management system that organizes the data of the transceivers and monitoring systems that continuously monitors the alarms, alerts, notifications and different important indications. Considering the smart grid architecture in mind, we need to categorize the communication network into short range and long range communications. When we take consumer side, our concern is the communication between home appliances, meters and the sensors deployed within the home premises. But this would not be the case when we are thinking of information exchange between the devices deployed at home and the grid station and we require a network that is suitable communication to distant places. Smart grid communication takes place at three different levels Home area networks (HANs), Neighborhood Area Networks (NANs) and Wide Area Networks (WANs). First one lie under the category of short range while other two are considered for distant communications.

2.2 Home Area Networks (HANs):

This network is just like personal areas network which is responsible for the interconnection of devices within a home or building. This network is suitable for short

range communication. Bluetooth, Wifi, Zigbee, 6LoWPAN and Z-wave are some of the short range communication technologies that can be used in HANs. IEEE has already defined the standards for all these technologies e.g. 802.11g for Wifi, 802.15.4b for Zigbee and 802.15.1a for Bluetooth respectively.

2.2.1 Zigbee:

A technology that is introduced with the aim of low power consumption with the alliance of different companies Samsung, Ember, Mitsubishi, Invensys, Philips and Honeywell. It has low data rates and hence consume less power that makes it suitable for remote monitoring, health care, building or home automation, reliable messaging and controlling sensors or devices. It is a suitable short range communication option provided that all the devices are interconnected. It offers greater compatibility and interoperability.

2.2.2 WiFi:

It is operated in ISM frequency band 2.4GHz and lies under IEEE standard 802.11b having latency rate of 3.2-17ms and maximum 11Mbps data rate [7]. IEEE also specified other different standards for wifi technology under the umbrella 802.11 are enhanced wifi (802.11g) uses DSSS (Direct Sequence Spread Spectrum) modulation and operated at 2.4GHz with increased data rate of 54Mbps. Similarly IEEE 802.11a uses OFDM (Orthogonal Frequency Division Multiplexing) with operating frequency of 5.8GHz, 600Mbps of data rate can be achieved using MIMO (Multiple Input Multiple Output) scheme under IEEE standard 802.11n and 802.11i uses Advanced Encryption Standard to address security issues in WLANs (Wireless Local Area Networks) [7]. Wifi is available almost in every electronic device e.g. mobile, laptop, computer and peripheral devices etc. It is basically upper layer protocol having IP as its predominant layer protocol that allows communication without any protocol translator.

2.2.3 Bluetooth:

Bluetooth is a wide spread available wireless communication technology that utilizes ISM band to exchange data over shorter distances. It is developed in 1994 by the engineers at Ericsson. After the launching of Bluetooth technology, different companies started using this technology and made a group termed as SIG (Special Interest Group) for the maintenance and enhancement of this technology. Piconet and Scatternet are the two topologies used for Bluetooth technology. Piconet is based on the concept that one mobile device must act as a master device while the rest will act as slaves. When two more Piconets combine together, they form a Scatternet. It can provide max data rate of 1Mbps with a limited range of only 10 m. It can be used for communication between home appliances, smart meters or sensors. But this technology is not much suitable for HANs because it has very short range of communication with limited number nodes that can be handled by this technology which is a serious constraint for using Bluetooth for Home Area Networks. Moreover interference is a big issue as it is operated in 2.4GHz frequency range where other technologies like wifi and zigbee is also operating. It takes some inherent security issues as well [8].

2.2.4 6LoWPAN:

It is an acronym for Internet Protocol (IPv6) and Low Power Personal Area network. This technology is launched targeting the interconnections of small devices and sensors using internet protocol. Motivation of introducing this technology is that the engineers were concerned that the smallest devices are left out from the IoT (Internet of Things). It uses mesh topology which increases its factor of scalability and also provides self-healing capability to the network. When the link gets broken from any point, it has the ability of re-routing the traffic of the damaged path.

2.2.5 Z-Wave:

A proprietary standard that is designed to transmits or receive small amount of data in residential as well as in business areas. Just like Zigbee it consumes low power and uses mesh topology. The main difference between these two technologies is that the two devices of Z-Wave are interoperable but on the other hand two Zigbee devices are not interoperable unless interoperability is pre-planned.

2.3 Comparison:

By doing the comparison of all the mentioned technologies of HANs, it is extracted that Bluetooth accessibility is easy, Wifi has the advantage of widespread availability having larger coverage area, 6LoWPAN added Internet Protocol (IPv6) to Wireless Personal Area Networks (WPANs), more number of nodes could be accommodated using Zigbee. It is also operated at low power which reduces the overall cost of implementing Zigbee for HANs or for smart metering infrastructure.

Table 2. 1: Comparison of HAN's technologies.

Comparison of HAN technologies for smart grid.

	ZigBee	Wi-Fi	Bluetooth	6LoWPAN	Z-Wave
Max. speed per channel	250 kbps (2.4 GHz) 40 kbps (915 MHz)	11–300 Mbps	Max. 1 Mbps	250 (2.4 GHz) 40 kbps (915 MHz) 20 kbps (868 MHz)	40 kbps
Reach	10–75 m	100 m (indoor)	10 m typical	Up to 200 m	30 m indoor, 100 m outdoor
Standard	IEEE 802.15.4	IEEE 802.11	IEEE 802.15.1	IETF RFC 4944	Proprietary
IP support	IPv6 only in SEP2	IPv6	Not presently, research continues	Yes, IPv6	Yes
Adoption rate	Widely adopted	Extremely high	Extremely high	Medium	Medium
Unique value	Low cost, low power usage, high number of nodes	High speed mature standards	Ease of access, no configuration requirement, secure connection	Benefits of both IP and Bluetooth, low power consumption	No interference from household devices

2.4 Neighborhood Area Network:

When we visualize the smart grid communication network architecture, NANs comes at the intermediate level of communication. This is the network that connects the HANs devices i.e. smart meters to the gateway network. NANs are of worth importance when

communication wing of smart grid systems are discussed. For end to end communication services, number of wired and wireless technologies are suggested for NANs. In this section we will discuss various communication technologies that can be used for NANs in smart grid.

2.5 Wired Technologies:

Wired links like copper or fiber optic cables provide secure data transfer with lower latency rate. Separated from the power lines, dedicated cables can be used for communication which offers increased capacity like in fiber optic cable. Optical fiber does not need intermediate relays, offers long distance communication without the need of amplification, have high capacity and inherently resistant to electromagnetic interference. However, communication technology selected for distributed areas must be adaptive to topology changes [9]. In addition to this, high deployment investment of wired solutions make them impractical for smart grid NANs. Furthermore, wired network also needs continuous checking and maintenance for working seamlessly.

PLC (Power Line Communication) is also strong candidate of wired communication solution for smart NANs. It is considered as the cost effective wired solution since it utilizes the existing power lines as a medium of communication. It seems to me more attractive solution as the electricity is already being delivering through these power lines and then this single medium is used for dual purpose using the existing infrastructure. But typically the PLC network was deployed only for the purpose to deliver electricity and they badly attenuate the information signal and lowers the quality by adding unintended noise/interference. Furthermore, there is no proper channel model suggested for PLC radio communication so far.

2.6 Wireless Technologies:

2.6.1 Satellite:

Satellite communication could also be a candidate for Neighborhood Areas Networks. Interconnection of rural areas grid devices and exchange of information from far off villages is the motivation of communicating via satellites. Use of Low Earth Orbit (LEO) would be preferred as compared to other higher orbit satellites because they accommodates high latency rate of greater than 300ms which is responsible for larger transmission delays. LEO satellites are 500-1500km above the earth surface having secure and reliable data transmission. There are very limited number of satellite network providers and international coordination is required for wide adoption of this technology. Maintenance and deployment cost is remarkably larger as compared to other wireless communication technologies.

2.6.2 WiMAX:

IEEE 802.16 or WiMAX is the acronym of Worldwide Interoperability for Microwave Access that is introduced for long range wireless networking for fixed as well as mobile users. It was envisioned to be a leading technology for internet communication that has the capability of replacing the wired cable internet, DSL and Wifi. But WiMAX has failed to replace the Wifi and other wireless technologies due to its higher cost. It has a latency rate of less than 100ms for round trip while coverage range is in the order of tens of kilometers. WiMAX can be used for NANs due considering its bandwidth and higher range of coverage. WiMAX has several usage in NANs like wireless automatic reading, detection of outage and monitoring etc. The main issue on deploying this technology for smart grid NANs is its costly radio equipment. Deployment of this technology needs optimized location setting of towers in order to minimize the deployment cost and high care of the equipment is also required.

2.6.3 Cellular Communication:

We are the witness of evolution of cellular communication networks from 2G to 4G. This technology is also in the competitor's list of smart grid NANs. Starting from 2G-GSM, provides data rate up to 14.4kbps and increased to 56-171 kbps in 2G-GPRS (General Packet Radio Service) and then 3G enabled networks provided 2Mbps data rate which is recently enhanced to 50-100Mbps in 4G LTE [10]. Our eye is witness of all this journey cellular networks towards technological advancement and the story does not ends here and research is being carried out to equip cellular networks with more features. Some of the state of the art technologies that are the focus of the researchers for the implementation of 5G are MIMO (Multiple Input Multiple Output), Massive MIMO, mm Wave communication and D2D (Device to Device) communication. Mentioned technologies are considered to be the key enabling technologies of 5G heterogenous networks. Considering the versatile nature and continuous evolution of network makes its suitable for communication infrastructure of smart grid. By using the existing infrastructure that is refined and have variety of features minimize the initial investment as well as its maturity reduces maintenance cost for running the deployed network. So, in a nutshell cellular networks must be preferred as compared to other communication network options available.

2.7 Why Cellular Network?

It is considered as one of the fine and standardized network used for communication purpose globally. It is continuously evolving, technology is stable and mature enough to trust to serve for emerging smart distribution grid. These networks operate in licensed bands have the capability to enable wide area communications for smart grid applications due to following reasons:

2.7.1 Maturity:

Use of widely adopted and mature communication infrastructure, reduces the risks of losses and maintenance cost. It is refined since decades and thus allows smart meters deployment as well as remote end points connection to a center monitoring system seamlessly. Reliable exchange of information is provided even for complex geographical regions i.e. coverage to far of rural areas and their link with the main power grid can be supported efficiently.

2.7.2 Dedicated Frequency Bands:

In unlicensed bands there is an issue of worst interference and noise that degrades the quality of communication severely. Cellular networks uses licensed frequency bands that yields better quality of communication as compared to unlicensed bands which comprises high threats to privacy of confidential energy data as well as compromise on information security.

2.7.3 High Performance:

Cellular networks are highly available networks providing lower latency, high data rate and high reliability. It can easily accommodate complex automation tasks of distributed grid system. Due to its larger coverage area, it is a good option for interconnection of remote devices located at different geographical locations to a central control and monitoring system. Cellular networks have ability to handle advanced smart grid applications and provides high redundancy, upgraded re-routing mechanism helps in timely outage management and preventive measures in case a power fault occurs.

Figure 2. 1: Neighborhood Area Network

Chapter # 3

3. Optimization of cellular networks and importance of user association

3.1 Optimization:

Optimization in one sentence is choosing the best element from available alternatives. It can be applied to any field or area. In order to apply optimization, first of all the problem must be clearly identified. After getting a clear idea about the problem, it must be modeled properly that maps perfectly in the category of a valid problem. If problem is identified correctly but not mapped in the right category of problems, it is impossible to get optimal result even if best technique of optimization is used. So, modeling of the problem is strongly bonded with problem identification in order to get best results out of it.

An optimization problem is further categorized into maximization or minimization problem. Objective function must be a minimization or maximization function. Optimization theory is directly linked with a large area of applied mathematics. Generally, it is the act of finding the best solution according to the objective function by setting some variable input values that is termed as domain. For that particular set of domain, getting best/optimal value for a real value objective function is optimization.

3.2 Modeling:

Making a sketch of a problem of real-life situation is modeling. The type of mathematical model is based on certainty, time reference, physical appearance, purpose of nature and method of solution. Particularly talking about engineering, there are certain methods and approaches which can be followed for optimization and they are:

3.2.1 LP (Linear Programming) Model:

This model perfectly works when the target is collectively linear and all the variables are linearly linked.

3.2.2 NLP(Non Linear Programming) Model:

A model which comprises linear as well as non-linear variables. It must have high degrees variables either in objective function or in constraints.

3.2.3 IP (Integer Programming):

Results the solution in an integer value having decision variables.

Allocation Model: Model that is suitable for allocation of resources to parties to get improved efficiency and better results.

3.2.4 One Dimensional Programming:

It comprises only one variable.

3.2.5 Multi-Dimensional Programming:

A model with more than one variable and decision variables as well.

3.2.6 Dynamic Programming Model:

A dynamic model have numerous decision stages and interrelated processes.

3.2.7 Game Theory Model:

A model in which two player/parties compete each other in achieving a particular goal. It basically works on the principle of mixed-strategy equilibria among two participants.

3.2.8 Goal Programming Model:

Any suggested model may include single objective as well as multi-objective optimization. But goal programming model has multiple goals or objectives.

3.2.9 Monte Carlo Simulation Method:

In optimization problems, this is one of an appropriate method to use as it works on the principle fairly near to true randomness in the algorithm with properly specified number of iterations. One result is obtained after doing specified iterations in order to make process more random in nature. It actually predicts the behavioral changes in a process over time which is somewhat near to the certain changes that are taking place in real life situations.

3.3 Model Limitations:

Numerous models that are discussed in the above section are widely used models. But still there are some limitations where these models or algorithms will not work. All such problems that contains impossibility or infeasibility are left unsolved. These algorithms or models cannot be applied on infeasible problems and it is preferred to leave them unsolved rather than wasting time and resources on them.

Optimization models can only solve the problems with quantifiable parameter. They do not have the capability to give solutions to intangible problems or problems with attributes containing qualitative nature e.g. emotions, human factor etc.

3.4 Procedure of Optimization:

After four or five decades, the engineers and researchers have proposed a general procedure or steps for modeling and solving optimization problems. It is the most acceptable general procedure which involves following steps.

1. Identify problem and collect data.
2. Refine data and formulate problem.
3. Select a suitable model for optimization.
4. Derive solutions for selected model.
5. Validate and test the solution.

6. Analyze sensitivity and control the solution.
7. Make decision and implement the solution.

Starting with the first step that is defining the problem. At start, may be the problem is in a vague form. So at that point relevant data collection will help the optimizer in clearing the problem. For example if a patient cannot explain his disease to the doctor completely and clearly then relevant data about that patient would help the doctor in diagnosing the problem of the patient clearly. Remember that while defining the problem, the boundaries of the problem must be declared at the same time. After defining and understanding the problem clearly, one should think about the goals or objectives. Objectives must be specified properly either there is a single or multiple objectives achievement. In the next step decision variables are to be declared. In optimization problem, decision variables are of worth importance. Whole decisions leading towards achievement of goals rely on decision variables. Any event is selected by the decision variables for moving the solution in the direction of objectives. Then comes the bounds on declared variables in order to make solutions possible in a controlled environment to get better efficiency. After clearly visualizing all of the above mentioned aspects, an appropriate model and suitable approach must be specified to get the optimal solution of the identified problem.

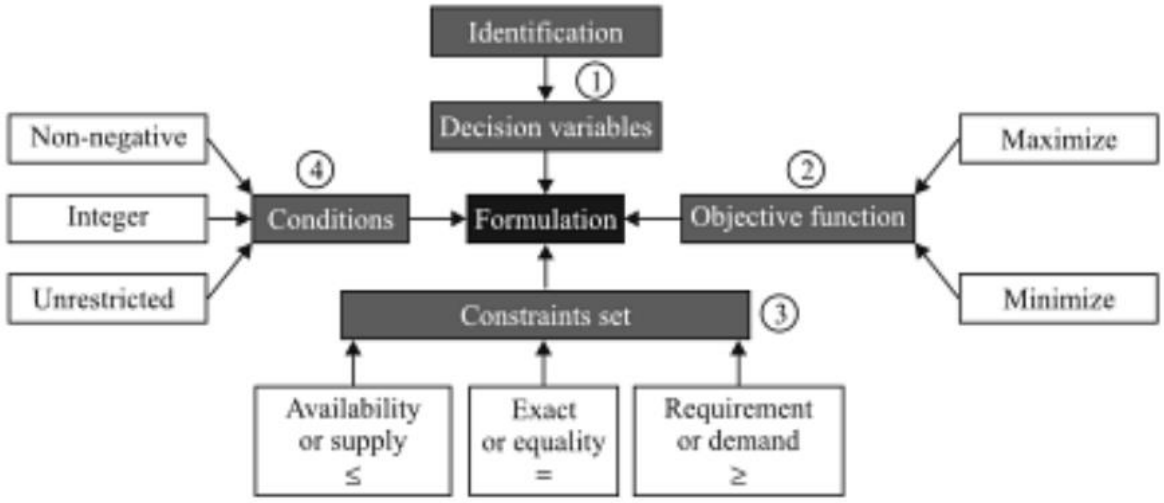

Figure 3. 1: Formulation of optimization problem

3.5 Mathematical Representation:

Optimization problem consists of an objective function, a decision variable as well as some constraints. Problems also exists without constraints that are much easier to solve as there is only objective function to minimize or maximize without any limitations.

min F(x) { An unconstraint minimization function }

max F(x) { An unconstraint maximization function }

min F(x)

subject to: x1+x2<5

x1,x2>=0 {Constraint optimization function}

3.6 Unconstraint Optimization:

This is the simple form of optimization problems where there is no limitations on the objective function. Only objective is straightaway focused. For example, data rate of a network has to be maximized i.e. max F(x)= B.W log (1+SNR). Now going towards the solution only objective i.e. data rate maximization has to be considered extensively throughout the approach. There is no limitation of threshold data or minimum power required for each user. So it belongs to a class of pure unconstraint optimization problems having no limitations or bounds on the objective function.

3.7 Constraint Optimization:

Optimizing an objective function considering some limitations on that function is constraint optimization. These constraints actually bounds the approach or technique used for solution that do not violate these conditions. Identification of the problem and then modeling that problem in such a way that its objective as well as constraints are

very well defined is very important things to consider before going towards the techniques for solution. If any of the constraint is invalid then you may get a solution in infeasible region. In this situation, optimal solution will never be achieved even by applying the best approach. In the above example of maximizing the throughput of a function. If we limit the objection in a sense that there is a threshold data rate that must be achieved by a user and a minimum requirement of power must be contained by any user to establish a connection with the BS. One may add another constraint that sum of power of all the users must not exceed the total power available. In this case, objective can be maximized when all the constraints are considered before applying the suitable technique for optimization. Constraints can be equality or inequality. Equality constraints are difficult to achieve as compared to inequality constraints. There is a relaxation when search space has reasonable area and the objective function have various optimal points at the boundary. Points at the boundary are fixed in equality constraints which are sometime where difficult to achieve. A general representation of a constraint optimization problem is as follow:

min F(x)

Subject to : C(x) = ci for all i {equality constraint}

Xi+xj <=9 for j = 1. . . . n { inequality constraint }

It is necessary for every optimization approach to satisfy both equality as well as inequality constraints in order to get minimum value for the objective function.

As already discussed that communication technology is the backbone of emerging smart grid systems. If communication is eliminated from smart grid then they work just like old traditional power grids. So, taking its importance into account, we want to optimize the performance of communication networks. In this chapter we will discuss

some of the different methods/techniques of optimizing the overall performance of the cellular networks.

3.8 Methods/Techniques for optimizing cellular networks:

Cellular networks have been evolved very drastically from 2G to 4G-LTE and still moving towards 5G technology with even more quick approach. In parallel with these technological advancements, the number of devices are also increasing at a very fast rate. This exponential growth lead us towards the necessity of deep thinking about how to improve the overall performance of the network in order to take more and more benefit out of it. As a result, vast research and numerous methods are suggested for optimization of cellular networks. Here are some of the suggested techniques.

3.8.1 Relay strategy and Resource allocation:

When we consider cellular networks or specifically wireless communication network with numerous source-destination pairs, the communication using relay nodes has a great importance in improving performance of the network. The relay nodes are located between source and destination, firstly it fetches information, decodes it and then this information is transmitted towards the destination. This particular strategy is termed as decode and forward (DF). Instead of DF, relay nodes also have another simple option that is simply amplify the received signal and forward it to the destination. This second mechanism is known as amplify and forward strategy (AF). Now the question arises that which strategy would be preferred for this cooperative transmission. Priority will be given to decode and forward (DF) strategy when relay is situated closer to source. As when it is closer to source, the signal to noise ratio (SNR) of received signal will be high. But when relay node is more closer to destination, the signal will have a lower SNR, then the signal must be amplified first and then transmitted towards destination i.e. AF strategy. In a nutshell, relay strategy has

a potential to improve the efficiency of the network within cooperated transmission [12]. Fig. 3.2 is a pictorial view of relay node strategy in which all the users are acting as a relay node.

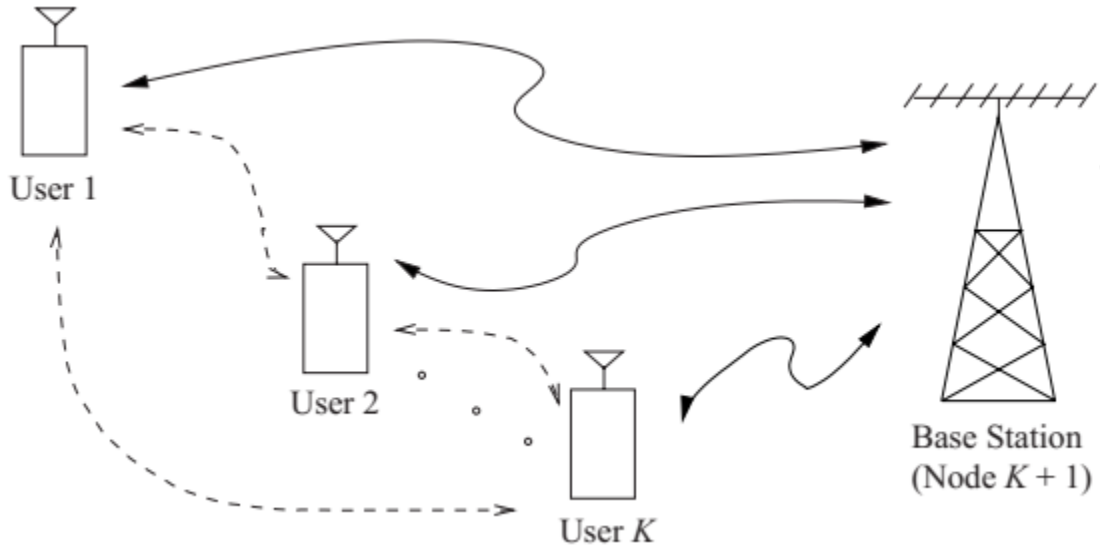

Figure 3. 2: Optimization using relay node strategy

Spectral efficiency always has a key role in optimizing the performance of wireless networks. Deployment of small cells i.e. pico and femto cells within macro cells is one of the important step in fulfilling the needs of tremendous growth of user. Heterogenous networks facilitates the reuse of spectrum by dense deployment of small cells [13]. As spectrum is a scarce source and it can be efficiently utilized by optimal resource allocation. Cognitive radio networks is considered as one of the extension of efficient utilization of resources/ spectrum using dynamic spectrum sensing as well as allocation of resources [14].

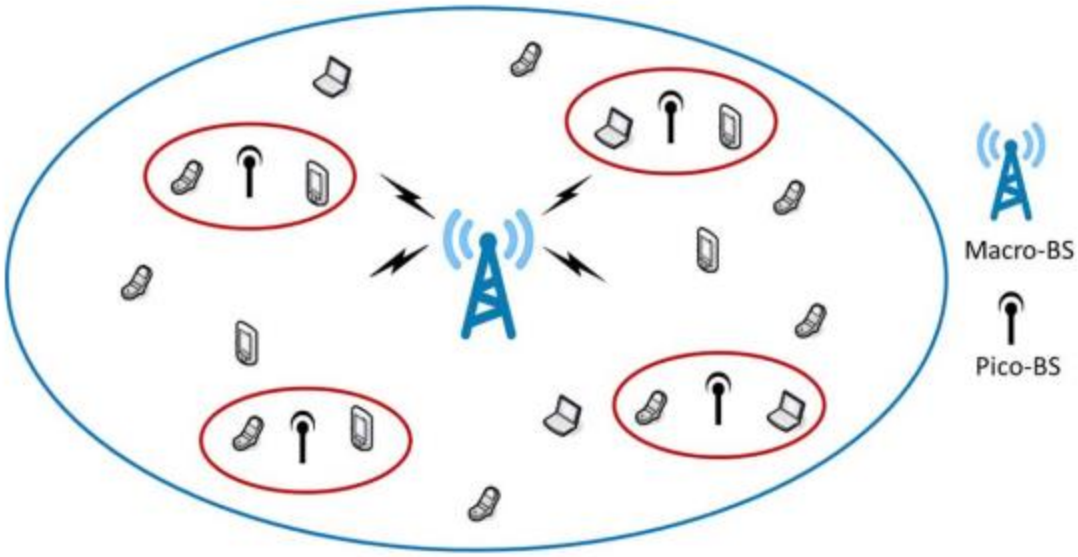

Figure 3. 3: Spectrum sharing in heterogenous network with one macro and four pico Base Stations.

3.8.2 Device to Device (D2D) Communication:

Telecom operators are worried about the accommodation of increasing demand of mobile users. So this need lead us towards seeking of some new paradigm that evolve the cellular networks towards more need based advancements. D2D came up as a paradigm shift in cellular communication. It is specified as the direct communication of two devices without the fully involvement of Base station (BS). BS is bypassed in such a way that the devices in D2D mode can directly transfer data or share information to each other. Only controlling mechanism will be provided by the BS but transfer of information will carried out directly among the devices in D2D mode. This offloads the traffic from BS and core network. D2D communication can occur in licensed cellular spectrum which is termed as inband communication as well as in unlicensed spectrum that lies under out band communication. Initially Qualcomm's FlashLinQ tried to implemented this architecture [15] and later it is investigated by telecom companies and 3GPP as well [16].

3.9 D2D modes:

3.9.1 Inband:

D2D communication using licensed cellular spectrum is inband D2D. most of the researchers suggested that use of licensed spectrum for both D2D and cellular communication is a better option to implement. It is termed as underlay inband D2D. Interference between D2D and cellular users is an issue in underlay inband. It is proposed for interference mitigation between D2D and cellular users in underlay communication is that D2D communication must be carried out within the dedicated portion of licensed spectrum. Communication using dedicated portion of licensed spectrum is overlay communication and resource allocation plays an important role here to avoid the wastage of spectrum. Some researcher considers inband communication better as in outband, devices face uncontrollable interference.

3.9.2 Outband:

In outband D2D, the devices directly communicate using unlicensed band. The advantage of using unlicensed spectrum is that it eliminates the interference problem of D2D and cellular users. It is also adaptable to other wireless technologies operating in unlicensed band e.g. Bluetooth, Wifi and Zigbee etc. On the other hand, D2D users have to suffer from severe interference in unlicensed band.

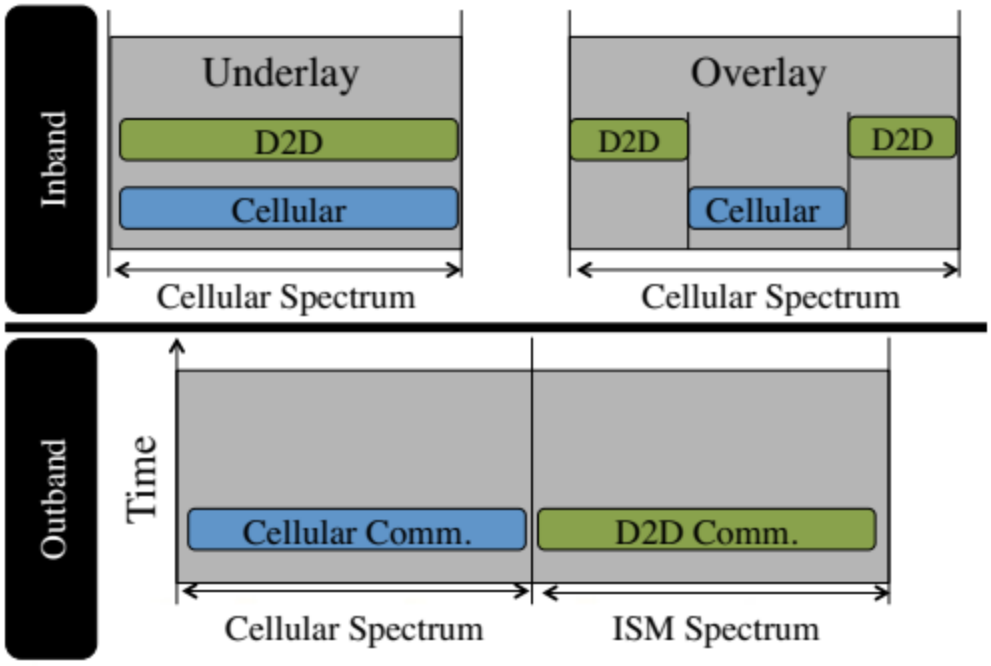

Figure 3. 4: Outband vs Inband D2D

3.10 MIMO and Massive MIMO System:

Multiple input multiple output system utilizes more than one transmitting and receiving antennas in order to improve the performance of the network. It enhances the capacity of radio link by using multiple antennas. Capacity enhancement is carried out by transmitting different symbols from different antennas while redundancy is improved by transmitting the same symbol using multiple antennas. MIMO system uses spatial multiplexing for transmission. In the same way, the number of antennas are increased up to few hundreds in massive MIMO system. Massive MIMO is just like MIMO system but its benefits are on a larger scale. Increasing the number antennas also increases the energy efficiency. Now energy can be projected even in smaller regions of the space. Using large number of antennas reduces fading and noise effects. Lower latency is the primary concern of every communication system. In wireless communication,

signal propagates through multiple paths due to reflection, scattering and diffraction. Multiple copies of transmitted signals are received at the receiver end which add up constructively or some times in a destructive manner. This destructive interference reduces the strength of the signal at a very lower level due to which fading dip occurs. In this condition terminal has to wait for the channel to change. Use of beamforming technique in massive MIMO can avoid these type of fading dips which in turn reduces the latency and helps in optimizing the performance of the network [17].

3.11 mm Wave:

Despite of the fact that wireless communication industry is continuously making advancements in spectral efficiency to best utilize the spectrum which is a very scarce source. But still wireless industry faces overwhelming spectrum demands for deployed setup. Almost after every decade the current generation network jumps towards the next generation network along with the evolution of computer and communication technology at the same rate. On the basis of this growth at a very tremendous rate, there is a prediction of severe congestion in wireless communication network in near future [18]. Considering the mentioned problems, mm wave can be consider as a key for the solution. It ranges from 30-300 GHz frequency. The demanding capacity and spectrum scarcity can be overcome by utilizing unused portion of the spectrum that is idle. Most focused portion for mm wave communication is 28 GHz, 38 GHz and 60 GHz [19]. Generally frequency band above 6 GHz is targeted for 5G research. This is actually the underutilized portion of the spectrum and placed into mm wave category.

Mm wave possess a lot of available spectrum but still there are various challenges in communicating within this portion. Communication in mm wave band suffers from severe propagation loss due to high carrier frequency. Suitable beam forming techniques could be a remedy for this huge propagation loss. It is also highly sensitive

to blockage by buildings, humans, furniture or any type of obstacles due to its weak capability of diffraction. In this high frequency range, the design of electronic components and circuits is also a challenging task. In addition to this, user mobility causes rapid fluctuations that require the change in channel state information accordingly. Capacity as well as channel state varies with the increase or decrease in distance between transmitter and receiver. Regardless of the challenges mm wave communication is a strong candidate for 5G networks. It is the best solution of spectrum overwhelming situations as well as increased capacity demands.

3.12 User Association:

The advancement from 1G-4G system is the true witness of the necessity of these steps for the world. According to a Cisco report, the data traffic all over the globe will increased by ten times from 2014-2019 with a rate of 24.3 exabytes per month by 2019. So keeping in mind this rapid growth of mobile data traffic, a paradigm shift is much needed for next generation network. There is a debate on 5G networks all over the globe which fuels a worldwide competition among competitors of next generation network. In this context, more than 10 projects have been launched by European commission with a total budget of more than 700 million pounds under 5G PPP (Public Private Partnership) project. China and South Korea are putting their best efforts to get the best solution for 5G networks for the world. Under the label of IMT-2020, Chinese government established three ministries for 5G promotions in Feb, 2013 [21].

Spectral efficiency must be 1000 times higher as compared to current mobile network, more secure and reliable communication with 10 times lower energy consumption, controlled privacy, these all are the goals of 5G network. D2D communication, massive MIMO, energy aware networks, densely deployed heterogeneous networks, full duplex communication and mm wave communication are the strong candidates for 5G network

in order to achieve the primary key performance indicators (KPI's) of the network. Obviously all the above mentioned technologies are of great worth in achievement of goals of 5G. But user association excels in worth as compared to other key enabling technologies of 5G network.

The decision making for a particular user to get connect with a specific base station (BS) is termed as association of a user with a BS or user association. This assignment procedure must be carried out critically bearing some decision making parameters in mind. The selection of parameter for user association is a crucial step. This step of selection is directly linked with the performance improvement of the network. This user association mechanism is attached with almost all the enabling technologies of 5G. This assignment or association must be handled differently for different communication technologies in order to improve the overall performance of the network [20].

3.13 Motivation/ Importance:

User association, a core concept in deployment of heterogenous networks. This problem arises when a user receives signal from different BSs. Its crucial stage comes when a user is at a point of overlapping region between two or more than two base stations. This is the point where an optimized association technique is required to get maximum output by best utilizing the resources. This one decision is of great importance regarding the performance of heterogenous networks. So an appropriate assignment strategy is the need of cellular network for the improvement of efficiency. That is why a class of user BS assignment problems have been discussed in parallel with every jump of a generation of cellular networks.

3.14 User Association Rules:

Generally user association is an assignment problem in which using a specific scheduling mechanism a user is assigned to BS. After the assignment, user get the

resources from that particular BS until it changes its location where it could be attracted by some other BS. Keeping in mind the nature of assignment problem, it seems to be computational complex. This complexity increases gradually while searching for optimal solution. Due to this high computational complex nature, a set of rules have been introduced that makes the problem simpler. As moving towards simplification will brought up a compromise on the performance of the network. But easy and simpler ruler are always considered as good rules. This trade off must be managed critically during the selection of rules for implementation.

Conventional and a simplest model that gained a lot of fame is the max-SINR (Signal to interference plus noise ratio) rule. In max-SINR, user get connected to a BS from where it gets maximum SINR i.e. max signal strength. The decision is merely based on transmit power of the BS. It looks good when homogeneous network is considered where there is no concept of small cells. But this typical rule have very bad performance with heterogenous networks. The dense Het Nets. have high power BS and low power small pico and femto BS as well. The transmit power of micro cells will always be less than macro BSs. So, bearing the max-SINR rule, all the users will get high power from macro BS and will establish their connections with the high power BS all the time letting the small cells idle. This will overload the traffic of macro BS keeping most of the small cells inactive. So taking power as the only parameter of user assignment is a bad approach [22]. Range extension is then introduced as a remedy for the challenges of max-SINR rule [23]. In this rule, decision has been taken on the basis of channel gain. User get connected to the BS with highest channel gain which enables the users near to small cells to establish a connection with the relevant SC (small cell). By comparison range extension made a prominent improvement in the performance of Het Nets. as compared to max-SINR rule. In short, the importance of BS assignment cannot be denied whenever there is a discussion on improving the effectiveness of cellular networks.

Chapter # 4

4. Literature Review

4.1 Description of Assignment Problem:

It is a finely proposed strategy that is made to maximize or minimize a predefined objective function. Following task assignment problem depicts a typical example of assignment problem. For example there are three tasks that are to be assigned to three employees i.e. employee 1, 2 and 3. There is some cost factor linked to every possible combination of an employee and the task. All the employees can done all the tasks at variable costs as shown in table 4.1. Now objective of the problem is to select a combination or assign the tasks to the employees that costs the least. Here the number of employees and the tasks are equal. So, it is a 1-to-1 assignment problem. Searching for a solution, a strategy is required for assigning a particular task to one of the three employees. Mathematically, this problem belongs to a class of discrete 0-1 optimization where a binary variable is must needed that works as the basis for decisions. This binary (0-1) variable is of core importance as it decides the assignment of tasks. The second thing that comes after this is the type of objective function. Sometimes assignment adds a fix gain to objective function targeting towards the maximization of objective function. Some existing algorithms like Hungarian could be a good option if the gain values are defined like in the above scenario shown in table 4. Assignment problem becomes more difficult in finding optimal solution when these gain values are not fixed.

Table 4. 1: Basic optimization scenario

Tasks / Employee	A	B	C
1	$30	$40	$60
2	$45	$35	$65
3	$65	$55	$35

4.2 Existing Work:

Taking into consideration the modern wireless communication network, it comprises a cellular structure. In this architecture the access nodes which are the BS's that provides the coverage to the users. A user must associate itself with a specific access node (BS) to get the services provided by the operator. Even a user can establish its connection with more than one BS at a time in coordinated multipoint (CoMP) technology [24].

With the emerging technology Het Nets (Heterogenous Networks) introduced in cellular technology have brought a remarkable change in cellular networks. The concept of cell splitting was introduced in Het Nets. In this advancement of architecture, new access nodes have been deployed in order to offload the traffic from the main BS i.e. macro BS. These micro cells are low power cells, and they hardly attract the users towards them due to their low power. Het Nets permits more frequent reuse of frequencies and have improved the overall throughput. But the main challenge in implementation of Het Nets. is the proper setting of transmit power for small cells. Power is an important factor in making a connection between a user and an access node. A conventional assignment strategy uses the SINR (Signal to Interference Plus Noise Ratio) value as a

decision parameter while establishing the connection with access node. This scheme is termed as max-SINR rule. This typical rule fails in balancing the traffic among macro and micro cells. For a small cell environment, load balancing is of worth importance. For this load imbalance [25] proposed a heuristic that adds a bias value to the lower SINR in order to push it to a comparable level to attract the users.

Formulations of BS assignment has been splitted up into two main dimensions. First one is the minimization of total transmit power considering the minimum requirement of SNR constraint for every user. The purpose of this power based formulation is to minimize the interference and this objective is significantly analyzed by [26-32]. Some other formulations include the rate based association. In this case, user is associated with the BS from where it gets the best data rate. Objective of this approach is to maximize the overall throughput of the network. A concept of microeconomics considers gain values as the utility and the gain function as the utility function. A noble approach termed as log utility maximization will be pursed in this thesis.

4.3 BS Assignment:

In already existing literature these BS assignment strategies has been enormously considered. The conventional method of max-SINR rule has some serious power issues during the deployment of pico/femto cells. The users are hardly attracted towards them under this conventional rule and load balancing is the major limitation of this particular procedure. This BS assignment problem is discussed differently by different researchers. So, there is variety of solution available for this problem. For example [33], targeted coordinate descent, dual coordinate descent as well as sub gradient method to get the association problem solved. This problem is extensively analyzed by [33] using different algorithms and distributed pricing approaches. Pricing variables are introduced in the objective function and their weightage actually helps in finding the optimal solution

for the defined objective function. Some of the work of [33] have already been published in [34].

For offloading the traffic in high power macro cells, [35] added a constant bias value to SNR in order to increase the coverage area. But in this technique, it is difficult to analyze the optimal bias term. Some other intuition methods like probabilistic approach in [36] and greedy algorithms in [37-39] have been discussed. [40] solved the problem using game theory. In [41] users does not share their channel state information (CSI) due to selfish reasons.

4.4 Greedy Method:

As discussed earlier that [37-39] analyzed BS assignment problem in a greedy manner. Like user terminals are always searching for the maximization of their own utility. Decision about the association of user to BS is purely based on each user's throughput to increase their own utility value irrespective of other parameters of environment. However controlling this mechanism is not an easy task. As each time, the certain number of users will switch their BS which leads to an oscillatory behavior as shown in Fig. 4.1.

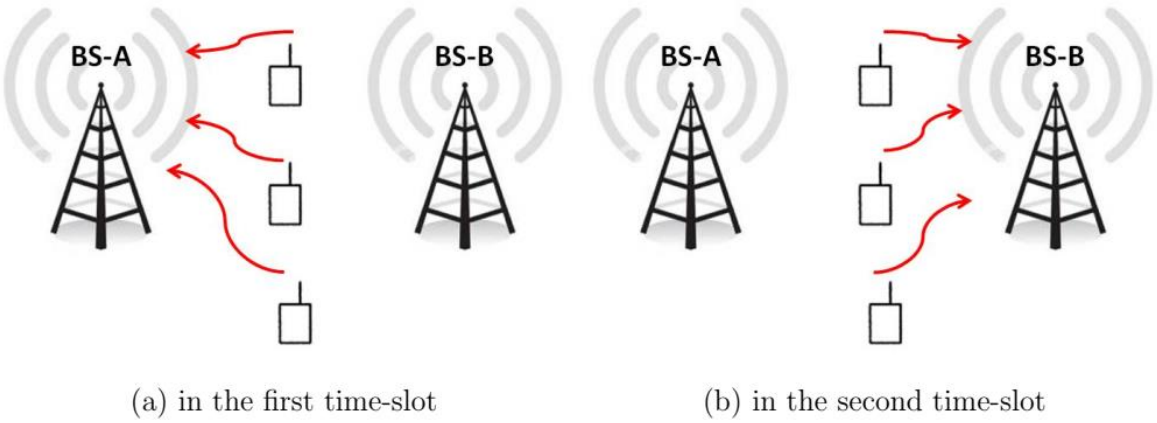

Figure 4. 1: Oscillatory behavior of greedy approach

Let aij is some utility parameter for the connection establishment in greedy method. In first time slot t1, all the users are connected to BS A. But in the next time slot t2, the users will establish connection with the second BS and so on. This switching is based upon the concept of maximizing utility of every users. Every individual user wants to take maximum data rate which results in back and forth switching of the users with different BSs in different time slots. So, this selfish algorithm have some serious flaws leading towards the oscillatory behavior within the network.

4.5 Probabilistic Approach:

[37] proposed a probabilistic approach for BS assignment. The assignment mechanism in this approach is done in a random manner. Decision have been made considering the spectral efficiency with specific BS. The probability of connection establishment of a user “i” with a specific BS “j” is directly related to its estimated spectral efficiency.

Table 4.2: Weightage for probabilistic approach

BS / Users	A	B
i1	5	3
i2	5	3
i3	5	3

4.6 Algorithms:

Variety of algorithms and optimization solvers are available for optimizing different set of problems. Opti toolbox in MATLAB is a built-in toolbox with numerous solvers for solving optimization problems. It has different solvers for linear, nonlinear, quadratic, mixed

integer linear (MINLP) and mixed integer nonlinear (MINLP) problems. One should identify the nature of the problem first and then correctly write or map that problem according to the solver's syntax. After doing this, run the solver and it will yield the optimal solution for that particular problem. Some of the most common solvers used for mixed integer nonlinear programming (MINLP) are NOMAD, BONMIN (Basic Open Source Nonlinear Mixed Integer Programming) and SCIP (Solving Constraint Integer Programs).

Before selecting the algorithm, it must be known by the individual that what is the nature of the problem and how many solvers and algorithms fits on that specific problem. The next step comes in which decisions are taken on the basis of convergence, time and results of that specific solver.

4.7 Fmincon:

It is one of the strong and fast optimization solver used for solving mixed integer nonlinear programming problems. It is used when you have both equality as well as inequality constraints and problem has variables with higher degrees. It has a specific syntax that will be discussed later. In order to use fmincon, first thing is to understand the syntax properly. Identify the category of the problem that either it is linear or nonlinear as well as integer or mixed integer. Once specified the above mentioned areas then next comes the correct mapping of the problem according to the given syntax of fmincon.

4.8 Mathematical Representation:

Taking general minimization function just to clear the concept of fmincon.

$$\min fun(x)$$

$$\text{s.t.} \quad A\,x \leq b$$

$$A_{eq}\,x = b_{eq}$$

$$LB \leq x \leq UB$$

$$ceq(x) = 0$$

$$c(x) < 0$$

$$x_0 = \text{initial guess}$$

In the above defined general representation, the scope of the solver is indicated. As it is a minimization problem. The essential requirements of fmincon are almost given in the problem. Now the question arises that how any problem can be mapped according to this general form as well as syntax of fmincon. For this a benchmark test problem has been used in order to make the things more clear. For example

$$\min x_1 x_4 (x_1 + x_2 + x_3) + x_3$$

$$\text{s.t.} \quad x_1 x_2 x_3 x_4 \geq 25$$

$$x_1^2 + x_2^2 + x_3^2 + x_4^2 = 40$$

$$1 \leq x_1, x_2, x_3, x_4 \leq 5$$

$$x_0 = (1, 5, 5, 1)$$

The above problem is a test problem termed as Hock Schittowski problem # 71 [42]. Objective is to do minimization of the defined function. S.t stands for subject to that is an indication of constraints. Fmincon can have equality as well as inequality constraints. Syntax for fmincon is as follows:

```
% optimize with fmincon
%[X,FVAL,EXITFLAG,OUTPUT,LAMBDA,GRAD,HESSIAN]
% = fmincon(FUN,X0,A,B,Aeq,Beq,LB,UB,NONLCON,OPTIONS)
x = fmincon(objective,x0,A,b,Aeq,beq,lb,ub,nonlincon);
```

First of all function is written in a new script as it is defined in the problem. MATLAB by default takes only minimization function but if objective is to maximize something then only putting negative sign before the function could yield the required result from the same algorithm. A and B here in the syntax represents the coefficients of inequality constraints as defined in C1. Aeq, Beq indicates equality constraints in C2. Lb and Ub are used for lower bounds and upper bounds while nonlincon hold all the nonlinear constraints of the problem. One important thing to discuss here is that almost every algorithm needs the initial guess at the star. As it is defined in the above problem i.e. x0. The solver takes the values of x0 as initial values or starting point for pursuing the further iterations to get the optimized results for a particular problem.

Chapter # 5

5. Joint user selection and BS association

5.1 System Model and Problem Formulation:

The main focus of this work is on BS and user assignment strategy that yields the maximization of our objective. Choosing the cellular network as the communication network for smart grid systems, the target is to improve the overall throughput by selecting the best combinations of users and BSs.

Considering a downlink cellular network, let *L* be the number of BSs and total *K* active users are there within the area covered by the cellular network. *i* and *j* are used for indexing a particular user and BS respectively i.e. *i 2* [1, 2, 3, ... , *K*] and *j 2* [1, 2, 3 , ... , *L*]. *W* is the total bandwidth (B.W) that is distributed among all the BSs. For making problem simpler, frequency flat power spectral density (PSD) levels and flat fading channels are assumed to make SINR values constant for all the frequencies. Channel between *ith* user and *jth* BS is denoted by *hij 2* C and *pj* is PSD level. Then SINR value for association of user i and BS j will be

$$SINR_{ij} = \frac{|\mathrm{h}_{ij}|^2 \; p_j}{\sum_{j' \neq j} |\mathrm{h}_{ij}|^2 \; p_{j'} + \sigma^2} \quad (1)$$

$\sigma 2$ = PSD of AWGN (Additive White Gaussian Noise).

In this thesis, we adopt sum log utility maximization objective for optimizing the throughput by selecting the best combination of users and BSs. If *kj* the number of user associated with each j BS, then each user connected to that specific BS will share 1*=kj* of frequency resource. The data rate of user i connected with BS j is calculated by

$$\mathrm{R}_{ij} = \frac{W}{kj} \log\left(1 + \frac{\mathrm{SINR}_{ij}}{\Gamma}\right) \quad (2)$$

Γ = SNR gap of user *i* that is determined by coding and modulation scheme.

Γ is assumed to be same for every user

Binary variable (1-0) *xij* is a decision variable used to determine whether user *i* is associated with BS *j* or not. Then objective function problem can be written as

$$f_o(X,R) = x_{ij} \log(R_{ij}) \quad (3)$$

Introducing a new parameter termed as utility parameter *aij* as

$$a_{ij} = \log\left(W \log\left(1 + \frac{\text{SINR}_{ij}}{\Gamma} \right) \right) \quad (4)$$

By substituting the value of *aij* into the objective function our BS assignment problem becomes

$$\max_{X,K} = \sum_{i,j} a_{ij} x_{ij} - \sum_{j} k_j \log(k_j)$$

$$subject\ to:$$

$$C1: \sum_{j} x_{ij} = 1, \quad \forall i$$

$$C2: \sum_{j} x_{ij} = k_j, \quad \forall j$$

$$C3: \sum_{j} k_j = K$$

$$x_{ij} \in [0,1], \quad \forall i, \quad \forall j$$

C1 indicates one user can be connected to one BS at a time i.e. one-to-one connection between user and BS. C2 shows the total number of users connected to each BS denoted by *kj*. C3 shows that all the users will be served.

5.2 Results and Discussion:

In this section, the ontained result from exhaustive search and specified algorithm (fmincon) will be discussed extensively. Our objective function is a maximization function that depends on the user and BS assignment strategy. Xij assigns a particular

user to a BS and *aij* is the utility parameter introduced to get an estimate of maximum capacity (data rate) of the network.

In Fig. 3 exhaustive vs optimal shows the value of objective function that is actually the throughput in monetary units. There is a comparison in this figure between exhaustive and optimal search algorithm. It can be observed by the bar graph that optimal algorithm cannot give better results than the heuristic approach. Heuristic approach will always be better as compared to any algorithm. As indicated in graph, overall throughput of the network increases by increasing the number of users because utility increases in this way by fixing the number of BSs. If the number of BSs are fixed and we keep on increasing the users, then after specific number of users, the utility of the network start decreasing. This decrement indicates the point of saturation with specific number of BSs that can be observed in case of optimal algorithm.

Fig. 4 shows the results of optimization algorithm i.e. (fmincon) used to observe the overall performance of the network with different combinations of users and BSs. For every set of users, the optimization algorithm calculates the objective function using the best assignment combination of users and BSs. There are three different graphs with uniqe throughputs which indicates that different number of BSs are used. As shown in Fig. 4(a), 2 BSs are fixed for this case. When we keep on increasing the number of users with fixed number of BSs, the network throughput increases till 50 users. After 50 users, the throughput decreases which indicates the overloaded traffic on 2 BSs. So, for best utilization, 2 BSs can accommodate max 50 users in order to get maximum overall throughput of the network. At this point we want to accommodate more users then number of BSs must be increased for getting maximum data rate. In the same way, if we increase number of BSs to 3 and 5 as indicated in Fig. 4(b) and 4(c), we can provide best services to 70 and even more number of users taking the best assignment strategy using fmincon approach. In a

nutshell, our algorithm selects users and BSs assignment jointly targeting the maximum throughput of the network.

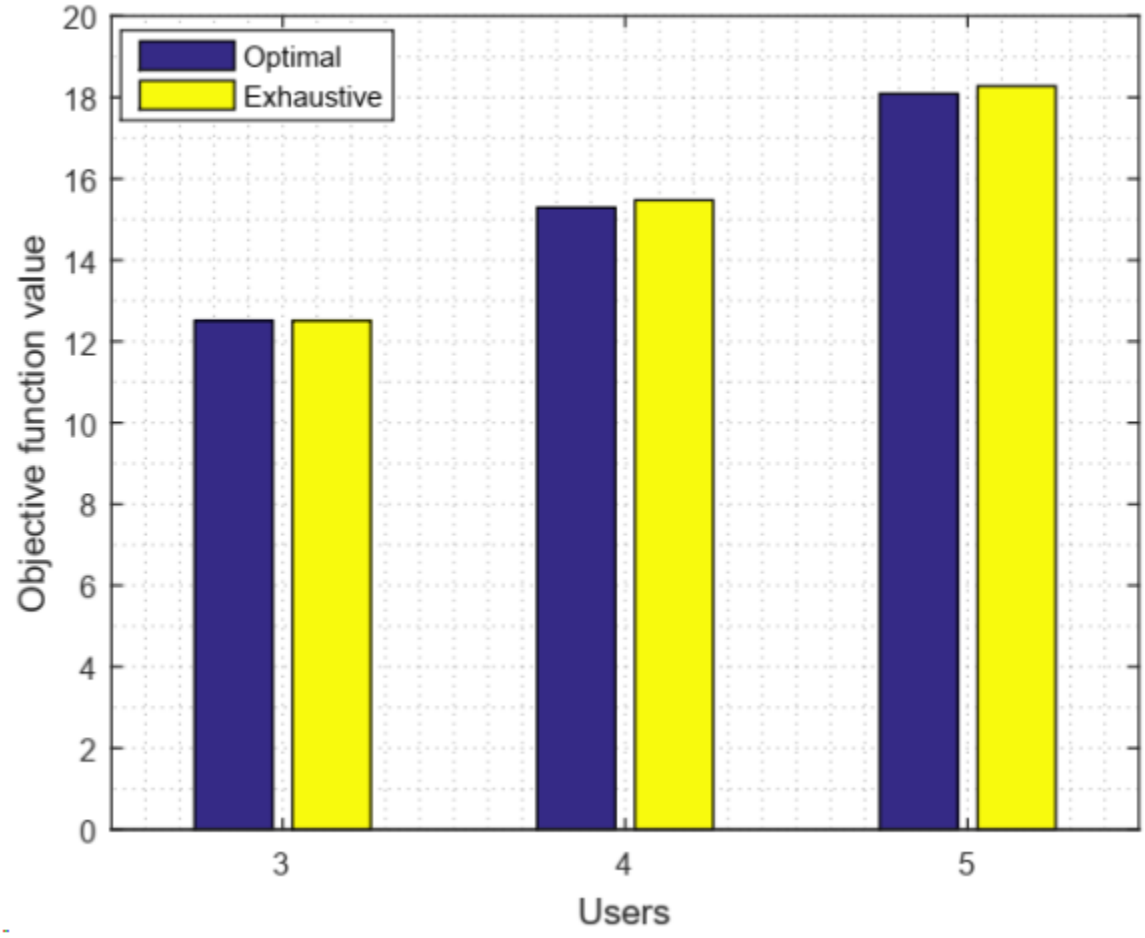

Figure 5.1: Optimal Vs exhaustive search

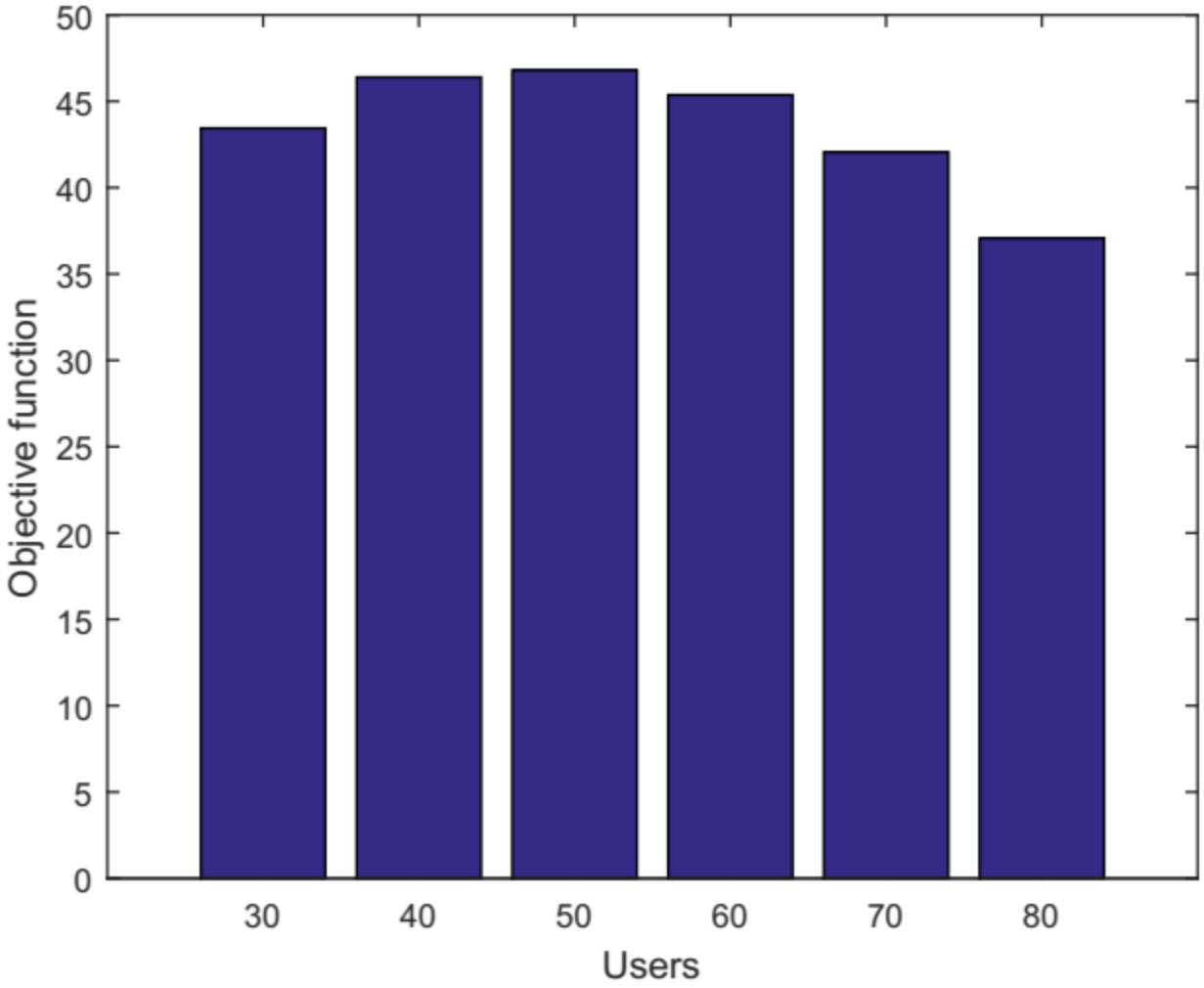

Figure 5.2a: 2 BSs

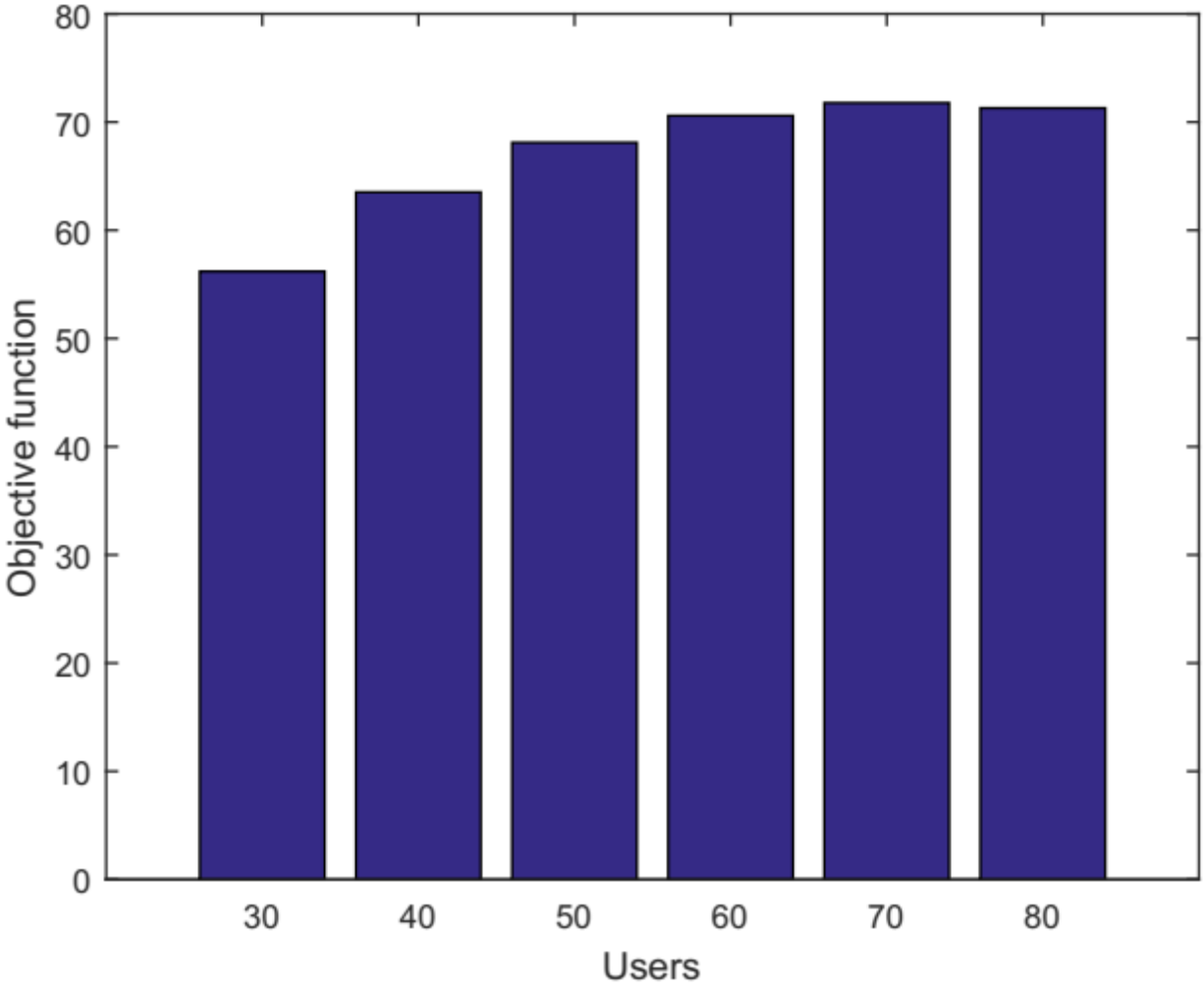

Figure 5.2b: 3 BSs

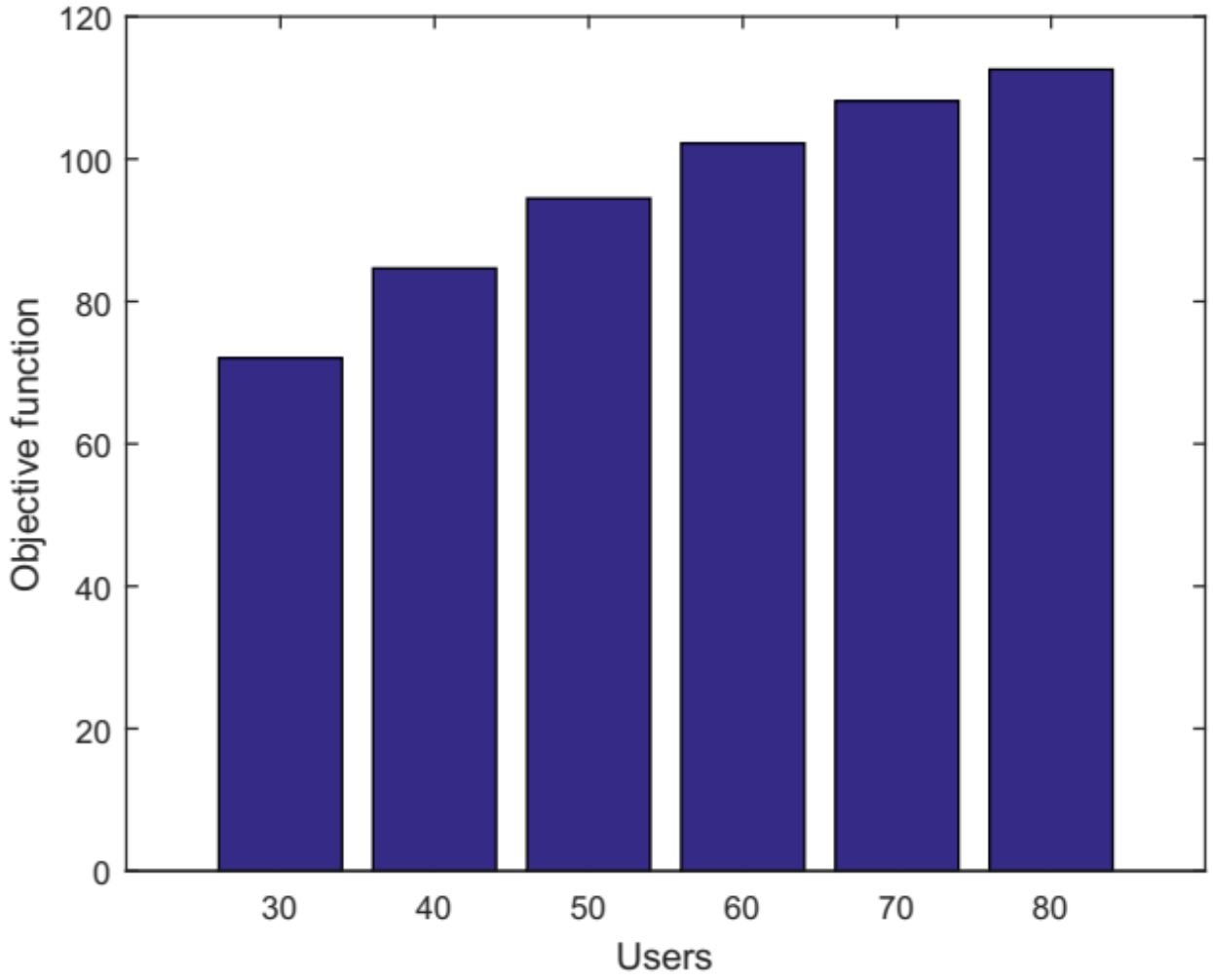

Figure 5.2c: 5 BSs

5.3 Conclusion and Future work:

This paper jointly optimizes user and BS association by selecting the best combination of user and BS that maximizes the overall throughput of the network. Implementing the heuristic approach gives the maximum results as compared to optimal algorithm. For any specific number of BSs, saturation point of user accommodation is identified. This saturation point is directly linked with the utility of the objective function and identify that maximum number of users that can be served using that fixed amount of BSs. It is clearly observed from the results that increasing the number users increases the overall throughput till saturation point and after this point any increase in user leads to decrement in the utility of the network. The optimization algorithm (fmincon) yield the

best combination of user and BS that is then used for getting maximum throughput up to certain saturation level. So, keeping the saturation point in mind, the performance of the network is optimized using optimal algorithm.

Jointly optimizing the power as well as user association could be a promoting extension of this work. Beamforming and power control are still two important aspects of a communication network that can make it more suitable and efficient for emerging smart grid communication network.

6. References

[1] Office of Electricity Delivery and Energy Reliability, “The Smart Grid, An Introduction”, US Department of Energy.

[2] Kim, Seong-Lyun, et al. "Guest editorial: Smart grid communications systems." IEEE Systems Journal 8.2 (2014): 417-421.

[3] Wang, Wenye, Yi Xu, and Mohit Khanna. "A survey on the communication architectures in smart grid." Computer networks 55.15 (2011): 3604-3629.

[4] Amin, Massoud. "Smart Grid." PUBLIC UTILITIES FORTNIGHTLY (2015).

[5] Rafiei, Mojtaba, S. Mostafa Elmi, and Akbar Zare. "Wireless communication protocols for smart metering applications in power distribution networks." Electrical Power Distribution Networks (EPDC), 2012 Proceedings of 17th Conference on. IEEE, 2012.

[6] Parikh, Palak P., Mitalkumar G. Kanabar, and Tarlochan S. Sidhu. "Opportunities and challenges of wireless communication technologies for smart grid applications." Power and Energy Society General Meeting, 2010 IEEE. IEEE, 2010.

[7] Wang, Wenye, Yi Xu, and Mohit Khanna. "A survey on the communication architectures in smart grid." Computer networks 55.15 (2011): 3604-3629.

[8] Gehrmann C, Persson J, Smeets B. Bluetooth security. Norwood, MA: Artech House Inc.; 2004

[9] Parikh, Palak P., Mitalkumar G. Kanabar, and Tarlochan S. Sidhu. "Opportunities and challenges of wireless communication technologies for smart grid applications." Power and Energy Society General Meeting, 2010 IEEE. IEEE, 2010.

[10] Feng, Zhao, and Zhang Yuexia. "Study on smart grid communications system based on new generation wireless technology." Electronics, Communications and Control (ICECC), 2011 International Conference on. IEEE, 2011.

[11] Yu, Chia-Hao, et al. "Resource sharing optimization for device-to-device communication underlaying cellular networks." IEEE Transactions on Wireless communications10.8 (2011): 2752-2763.

[12] Ng, Truman Chiu-Yam, and Wei Yu. "Joint optimization of relay strategies and resource allocations in cooperative cellular networks." IEEE Journal on Selected areas in Communications 25.2 (2007).

[13] Tang, Jie, et al. "Resource allocation for energy efficiency optimization in heterogeneous networks." IEEE Journal on Selected Areas in Communications 33.10 (2015): 2104-2117.

[14] Ng, Derrick Wing Kwan, Ernest S. Lo, and Robert Schober. "Multiobjective resource allocation for secure communication in cognitive radio networks with wireless information and power transfer." IEEE transactions on vehicular technology65.5 (2016): 3166-3184.

[15] Wu, Xinzhou, et al. "FlashLinQ: A synchronous distributed scheduler for peer-to-peer ad hoc networks." IEEE/ACM Transactions on Networking (ToN) 21.4 (2013): 1215-1228.

[16] Asadi, Arash, Qing Wang, and Vincenzo Mancuso. "A survey on device-to-device communication in cellular networks." IEEE Communications Surveys & Tutorials 16.4 (2014): 1801-1819.

[17] Gupta, Akhil, and Rakesh Kumar Jha. "A survey of 5G network: Architecture and emerging technologies." IEEE access 3 (2015): 1206-1232.

[18] Rappaport, Theodore S., et al. "Millimeter wave mobile communications for 5G cellular: It will work!." IEEE access 1.1 (2013): 335-349.

[19] Niu, Yong, et al. "A survey of millimeter wave communications (mmWave) for 5G: opportunities and challenges." Wireless Networks 21.8 (2015): 2657-2676.

[20] Liu, Dantong, et al. "User association in 5G networks: A survey and an outlook." IEEE Communications Surveys & Tutorials 18.2 (2016): 1018-1044.

[21] IMT-2020 (5G). [Online]. Available: http://www.imt-2020.cn/en/

[22] Ghimire, Jagadish. "Heterogeneous Cellular Networks: from Resource Allocation to User Association." (2015).

[23] Khandekar, Aamod, et al. "LTE-advanced: Heterogeneous networks." Wireless Conference (EW), 2010 European. IEEE, 2010.

[24] 3GPP TR 36.814, “Further advancements for E-UTRA: physical layer aspects,” 3GPP-3rd Generation Partnership Project, Mar. 2010.

[25] Guvenc, Ismail, et al. "Range expansion and inter-cell interference coordination (ICIC) for picocell networks." Vehicular Technology Conference (VTC Fall), 2011 IEEE. IEEE, 2011.

[26] Smolyar, Lev, Itsik Bergel, and Hagit Messer. "Unified approach to joint power allocation and base assignment in nonorthogonal networks." IEEE Transactions on Vehicular Technology 58.8 (2009): 4576-4586.

[27] Wang, Jui Teng. "SINR feedback-based integrated base-station assignment, diversity, and power control for wireless networks." IEEE Transactions on Vehicular Technology 59.1 (2010): 473-484.

[28] Pennanen, Harri, Antti Tölli, and Matti Latva-aho. "Decentralized base station assignment in combination with downlink beamforming." Signal Processing Advances in Wireless Communications (SPAWC), 2010 IEEE Eleventh International Workshop on. IEEE, 2010.

[29] Nguyen, Duy HN, and Tho Le-Ngoc. "Joint beamforming design and base-station assignment in a coordinated multicell system." Iet Communications 7.10 (2013): 942-949.

[30] Nguyen, Duy HN, and Tho Le-Ngoc. "Joint beamforming design and base-station assignment in a coordinated multicell system." Iet Communications 7.10 (2013): 942-949.

[31] Yates, Roy D., and Ching-Yao Huang. "Integrated power control and base station assignment." IEEE Transactions on vehicular Technology 44.3 (1995): 638-644.

[32] Hanly, Stephen V. "An algorithm for combined cell-site selection and power control to maximize cellular spread spectrum capacity." IEEE Journal on selected areas in communications 13.7 (1995): 1332-1340.

[33] Shen, Kaiming, and Wei Yu. "Distributed pricing-based user association for downlink heterogeneous cellular networks." IEEE Journal on Selected Areas in Communications 32.6 (2014): 1100-1113.

[34] Shen, Kaiming, and Wei Yu. "Downlink cell association optimization for heterogeneous networks via dual coordinate descent." Acoustics, Speech and Signal Processing (ICASSP), 2013 IEEE International Conference on. IEEE, 2013.

[35] Guvenc, Ismail, et al. "Range expansion and inter-cell interference coordination (ICIC) for picocell networks." Vehicular Technology Conference (VTC Fall), 2011 IEEE. IEEE, 2011.

[36] Lee, Soohwan, et al. "Base station association in wireless cellular networks: An emulation based approach." IEEE Transactions on Wireless Communications 11.8 (2012): 2720-2729.

[37] Madan, Ritesh, et al. "Cell association and interference coordination in heterogeneous LTE-A cellular networks." IEEE Journal on selected areas in communications 28.9 (2010): 1479-1489.

[38] Ramjee, Tian Bu Li Erran Li Ramachandran. "Generalized proportional fair scheduling in third generation wireless data networks." IEEE INFOCOM. 2006.

[39] Son, Kyuho, Song Chong, and Gustavo De Veciana. "Dynamic association for load balancing and interference avoidance in multi-cell networks." IEEE Transactions on Wireless Communications 8.7 (2009).

[40] Jiang, Libin, Shyam Parekh, and Jean Walrand. "Base station association game in multi-cell wireless networks (special paper)." Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE. IEEE, 2008.

[41] Hong, Mingyi, and Alfredo Garcia. "Mechanism design for base station association and resource allocation in downlink OFDMA network." IEEE Journal on Selected Areas in Communications 30.11 (2012): 2238-2250.

[42] http://apmonitor.com/che263/index.php/Main/MatlabOptimization