Tracking Everyone and Everything in Smart Cities with an ANN Driven Smart Antenna

Herman Kunsei, Paul R. P. Hoole, K. Pirapaharan, and S. R. H. Hoole

Abstract

Smart cities require the application of human brain-like intelligence systems for sensing, monitoring, decision making and action. In this chapter this scenario is addressed in a two-fold manner. First, the function and requirements placed upon telecommunications systems are described and the future directions and challenges are discussed specifically in relation to the sixth generation (6G) wireless systems which are both different from the wireless systems up to 5G and are expected to play a critical role in smart cities. Secondly, the chapter presents a novel artificial intelligence (AI) driven smart antenna that is both computationally efficient and low on memory use, with the ability to track machine to machine, M2M, and machine to human, M2H, communications in the smart city. Smart cities depend on smart Internet of Things (IoT) management to ensure that infrastructure is monitored and corrected if there is a failure as in the case of emergency systems. This chapter discusses the application of AI in the physical layer in addressing connectivity issues of IoT in the wide area network and cellular systems landscape. The chapter address the connectivity of wireless systems of low power consumption, enhanced coverage, low latency communications, small bursts of data and the number of devices (running into hundreds of thousands). Central to the IoT management system is a novel artificial neural network (ANN) driven antenna that may rapidly be set for continuous rotating communication with several machines or smartphones, as well as focus in specific areas of intense or critical activity. Furthermore, the ANN driven array smart antenna will be coded to track moving targets.

Keywords

Artificial intelligence • Machine learning • 6G • Wireless networks • Internet of Things • Smart cities • Artificial neural network • Smart antennas

1 Introduction

For 21 centuries, humans have maintained their cities for their survival with very little real-time feedback from the cities. The smart cities of today and tomorrow will be more connected in terms of human to everything and everything to everything. The objective of the massive connectivity is to enable the smart city to adapt and offer the best possible service to human settlers. This implies that the buildings will be smart, homes will become smart, means of obtaining health care will become timely and smart, vehicles will become greener and smarter, learning will become smarter, the way people live will be enhanced and comfortable (Pelton & Singh, 2019). Collectively, the smarter the services and infrastructure of a city becomes, drives the city to become a smart city. The services and infrastructure become intelligent through the sharing of information, learning from the data collected and making informed decisions. These functions and others can only be efficient if the communication systems are intelligent.

This chapter focuses on the use of intelligent communication systems to enhance and enable the performance and

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operations in a smart city. A smart city is a sustainable and digitally intelligent city that employs ICT and other digitally driven transducers and sensors to meet the needs of city dwellers, both present and future, improving the quality of life and the efficiency of the businesses, industries and homes that make up the city (Mahmood & Smart, 2018; Pelton & Singh, 2019; Sun et al., 2018). As such telecommunication systems play a central role in the makeup of the smart city. More specifically, intelligently adaptive sensors and transducers at which the wireless or wired communication systems terminate, play a critical role in smart cities (Hoole, 2020). In this chapter, we shall give a specific example of a new, memory efficient and fast array antenna system that may be used with both sensors and transducers at the moving of node points of a smart city. The nodes may be stationary, a house for instance, or mobile, such as a transport vehicle. The AI enabled smart antenna reported herein may be used for both stationary and mobile machine-to-machine (M2M) or device-to-device (D2D) wireless communication systems (Marzuki, et al., 2021; Pirapaharan et al., 2021; Senthilkumar, et al., 2021).

Such intelligent, fast, and low-on-digital-memory-use antennas become the critical eyes and ears, as well as the transducer driving muscle termination points of a smart city. These antenna terminal points are integral parts of smart buildings, smart mobility, smart energy, smart water, smart waste, smart management and smart digital layers of a smart city. These various activities of a smart city increase since 60% of the world population is expected to dwell in cities, with a decreasing percentage in rural areas. In 2050 the percentage of city dwellers is expected to increase to 75%. And all these cities spread over the globe are expected to occupy only 5% of the surface of the earth. With a high density of people their various demands and activities necessitate an integrated city structure that uses reliable broadband communication networks and an efficient ecosystem for the wide variety and fast operating digitally driven systems that are all interconnected by the Internet or the application of IoTs (Cicirelli et al., 2019; Mahmood & Smart, 2018).

The AI array antenna and associated wireless communication system form the fundamental building block that connects all layers of the IoT devices including M2M communications and data processing, for a wide range of interconnected applications. These applications include: (a) the logistics business analytics, predictive maintenance and high level factory automation of industry, (b) remote monitoring and user consumption control of utilities including gas, electricity and water, (c) traffic monitoring, improving road safety, driverless transportation and public safety of transportation, (d) wearables for games and leisure industries, and fitness and health monitoring, (e) residential, industrial and public security, remote surveillance, remote tracking, alarms, and protection of public infrastructure from vandalism, damage and theft, and (f) clean environment, green energy, smart homes and smart buildings (Pelton & Singh, 2019).

The chapter shall first survey the intelligent communications systems that are available for use in smart cities. The next section will specifically focus on wireless systems that may be used for both long distance and short distance communication, namely the 5G and future 6G wireless systems. Some keys research challenges in effective communications system are discussed. In the final section of the chapter, we shall present a novel, fast and low memory smart antenna system that uses AI techniques to generate narrow, rapidly steerable beams for IoE communications in smart cities. We discuss three applications of smart cities that can benefit from the ANN-enabled smart antenna.

2 Smart City and Intelligent Communications

The Smart city Internet of Things (IoT) system requires highly reliable optical communication systems or wireless systems for remote M2M communications, monitoring and control. The advantages of a wireless system compared to a wired system are that its set up costs are relatively low and changes at existing sites are more easily done, whereas the artificially intelligent 5G smart antenna reported in this chapter is of immense help in overcoming the two important disadvantages of wireless communications systems. There is potential for interference between the wireless signals in free space and signals of sensors and other networks. Moreover, the directive and rotatable beams of the advanced beamformers presented herein help overcome delays in communicating alarm and emergency data, as well as tracking and communicating with moving targets such as vehicles. Furthermore, intelligent antennas help in network virtualization, where there is a need to operate different networks with different characteristics and functions. With multiple network nodes with steerable, narrow beam, adaptive antennas, it is possible to optimize virtual network routes, as well as to optimize the virtual network capacity allocation based on communications traffic. In Fig. 1 is shown the four major components of a smart city. These are the home, industry, commercial/business and city ecosystems (Pelton & Singh, 2019). Each has its own specialized functions and requirements in which people centered, integrated and context specific design of the city is required. The brain that enables the effective function of a smart city is its communication system that includes the 5G wireless, WIFI, LTE, WiMAX, Femtocell and optical fiber communications systems. Of these the two most important systems are the 5G (and future 6G) wireless and wired optical communications systems (Sun et al., 2018).

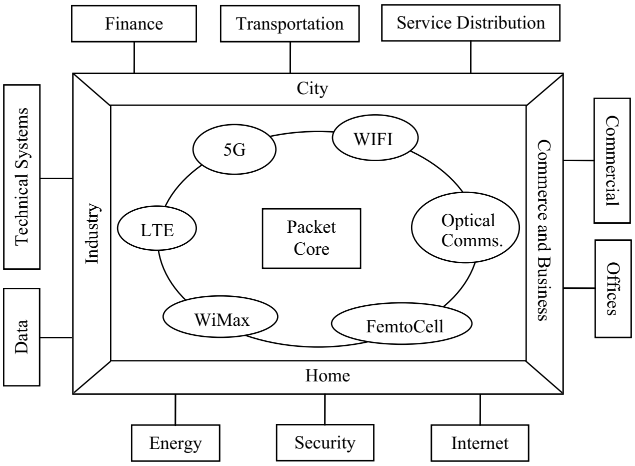
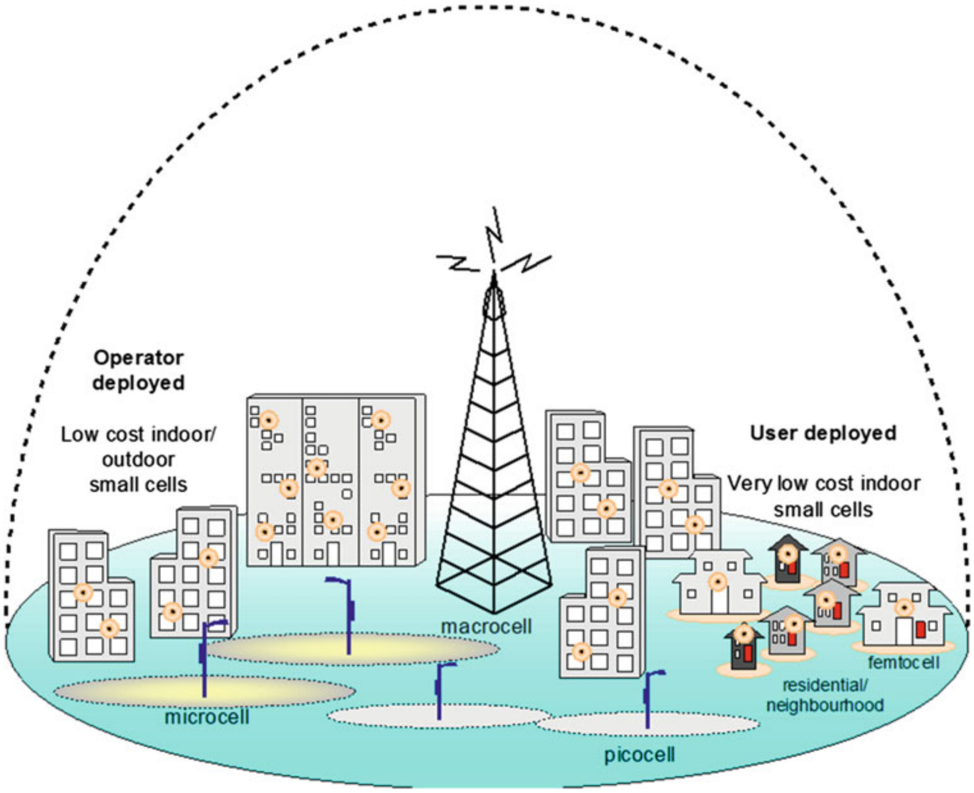


Fig. 1 Smart city integrated by the communications, command and control networks

In Fig. 1 is shown how the communications system is central to the smart city in all its various domains, namely, the city, homes, industries, and business and commerce. All four domains include the following technologies: Internet of Things, M2M and H2H communications, smart electric grids, driverless transport, virtual technologies, artificial intelligence and automation; besides cyber security, tele-education, tele-health services and telemetry architecture. In every single one of these wireless systems smart antennas will play a key role in wideband as well as narrow band operation of the smart city. Therefore, in whatever aspects of the planning of the city, due consideration needs to be given to the full exploitation of the developing technology of intelligent array antennas discussed in this chapter, since this forms the node points of the communications network that integrates all the different technologies. Hence intelligent wireless communications systems are specifically expected to play a crucial role in smart city planning, which includes, meeting the needs of the citizens, and enhancing competitiveness, sustainability, supportive infrastructure and service industry, security and artificial intelligence technologies.

The deployment of dense small cells overlaid in the existing HetNets (Fig. 2), has been identified as a feasible strategy to expand the network coverage and address the explosive growth of mobile data traffic. Relying solely on macro-cell base stations is no longer an effective strategy, as the data volumes with associated uneven traffic distributions have increased tremendously in recent times. Moreover, deploying additional macro-cells would not be a viable solution, due to their high installation cost and the lack of suitable sites for deployment. Thus, modified networks are required in which smaller cells can be deployed within the existing macro-cell area to form HetNets (Marzuki et al., 2021).

Fig. 2 An example of HetNet deployment (Marzuki et al., 2021)



By reducing the cell size, the use of the limited, available bandwidth from the already scarce spectrum resources can be optimized by adopting frequency reuse. Moreover, as these cells offer local traffic off-loading to a smaller number of users, larger portions of resources can be accommodated for their associated users. The shorter distance between these low-powered base stations and user devices prolongs user battery life, thus increasing both the energy efficiency and signal-to-interference-plus-noise ratio (SINR) due to the low loss path. Although small cells (i.e., microcells, picocells and femtocells), can facilitate high bandwidth and wireless user ubiquity, densely deployed networks introduce a new set of challenges such as backhaul connectivity, resource allocation and energy management issues. Moreover, small cell densification also implies high inter-cell interference (ICI) among these cells due to their close proximity and arbitrary deployment (Marzuki et al., 2021).

Small cell backhaul solutions can be either wired or wireless, depending on the required network coverage, installation complexity, and associated cost (Pirapaharan et al., 2021). Thus, providing high-capacity connectivity between small cells and core network may require extensive planning before an optimal solution can be achieved. Wired connectivity is straightforward and is commonly used in small cell deployments. However, when these small cells are deployed outdoors, the backhaul connectivity becomes more complex. This raises a concern, as 75% of outdoor small cells may be backhauled by using wireless connectivity in the future. Therefore, efficient backhaul solutions utilizing wireless links must be designed to address both 5G spectral and power requirements. In the 4G small cell deployment, user traffic demand is backhauled to the network operator via broadband gateways such as DSL cables. The absence of dedicated wired backhaul links can diminish the network real-time Quality of Services (QoS) (Marzuki et al., 2021).

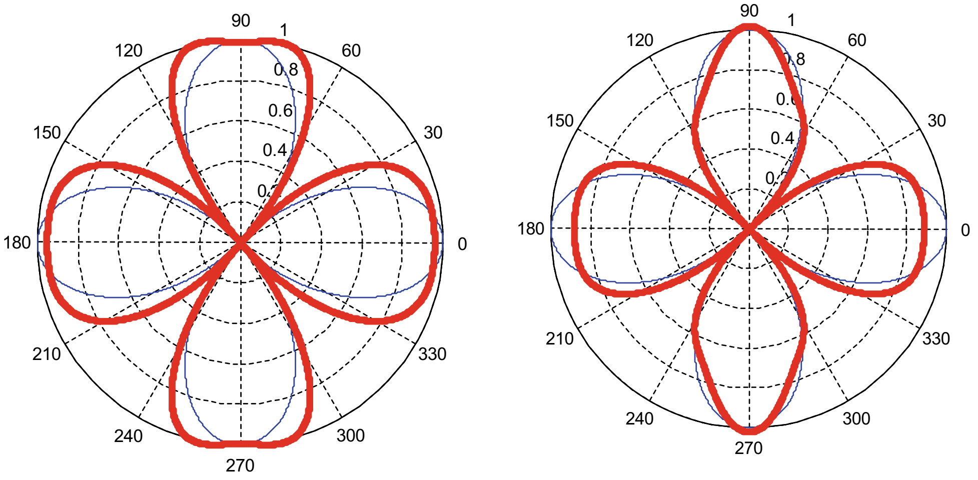
Indirectly, this will cause the sub-optimal small cell access point placement issue, considering that a high cost is involved in connecting these small cells to an existing infrastructure. Thus, the main motivation in deploying small cells in cell edge regions, and in areas with high user density, will not be realized.

Several studies have focused on determining the optimal small cell deployment while considering different performance metrics. To realize the random and flexible deployment of these small cells, optimal cell placements in an existing infrastructure must be accomplished. A theoretical framework for small cell placement is designed to maximize the network spectral efficiency and mitigate co-tier interference. An optimal solution of backhaul design for small cell networks is developed by taking the network requirement constraints, such as coverage and capacity, into consideration. Small cell placement strategies are used to achieve a fault-tolerance network with the use of small cell self-healing features (Marzuki et al., 2021).

Despite the potential of small cells in delivering high data rates to the ever-increasing number of users, another research challenge remains, particularly with respect to resource allocation to users in small cells. Small cells, specifically femtocells, are deployed by the end user with minimal intervention from network operators. Short distances between small cells cause overlapping coverage areas and hence inefficient resource management and associated interference problems. In such scenarios, inefficient resource management will result in severe interference problems. A cluster-based resource allocation scheme has been developed for femtocell-assisted macro-cellular networks. This scheme is developed to mitigate both cross- and co-tier interference in the network. Other solutions proposed are a dynamic resource allocation approach and fractional frequency reuse.

It is anticipated that small cell densification will play a critical and growing role in future wireless communications, by enabling the network service providers to deliver high data rates through increased frequency reuse, enlarged coverage areas, and greater spectral and energy efficiencies. For densification, the wireless antenna beams need to be narrowly directed in specified directions and be able to track in the case of mobile M2M communications. Such an antenna is shown in Fig. 3, where the antenna beams, for instance, may be directed along long narrow roadways communicating with moving vehicles. It is seen that there is maximum radiation over a wider area than what is required by the desired beam (Senthilkumar et al., 2021). However, this is rectified by increasing the number of elements from five to seven, thus getting greater accuracy at the cost of computational time and the cost of adding extra elements. As we have expected, with an increased number of elements, adaptive array beamforming is much closer to the desired beam. However, the amplitudes in the 0 ° and 180 ° directions are better for the five element array antenna than for the seven element array. This is due to the characteristics of the desired beam selected. In order to have the comparison of accuracy of weights optimized using the SNWOM method with the weights optimized using the traditional LMS method, the weights are calculated for five element and seven element array smart antennas using LMS optimization. The radiation patterns for five and seven elements optimized from LMS methods are shown in Fig. 3a and Fig. 3b, respectively (Senthilkumar et al., 2021).

The communications systems that are widely employed in smart cities include the following six technologies: (i) The IEEE 802.15.4 which defines the physical layer (PHY) and medium access control (MAC) layer specifications for low rate wireless personal area network, (ii) WiFi where the IEEE 802.11 standard providing high data rate



a. Five elments

b. Seven elements

Fig. 3 Comparison of radiation patterns between optimized beam and desired beam obtained by SNWOM (Senthilkumar et al., 2021)

transmission (1 Gbps) for a limited number of interconnected devices over a short distance, at 2.4, 5 or 60 GHz at bandwidths ranging from 20 to 160 MHz, (iii) Bluetooth providing a low-cost wireless communications personal network over distances less than 100 m, at 2.4 GHz, (iv) RFID for short range connectivity for identification purposes, (v) Low Power Wide Area Network (LPWAN), connecting devices over a wide area, long range data communication, up to distances of 10 km. Some of the well-known systems are LPWAN, Ingenu, LoRa, NWave, Platanas, SigFox, and weightless, (vi) Cellular systems: These were originally used for H2H, human to human communications, and now extended toward M2M communications. These are the most powerful wireless systems, allowing for wide coverage, easy deployment, access to dedicated spectrum and high security level. The recent 5G systems, making use of intelligent, steerable beam antenna reported in this chapter, allow for narrow band operation, power saving modes, multihop and group based communications, enhanced coverage and ultra-reliable, low latency communications. The system handles a massive number of devices, including mobile devices, as well as small bursts of data (Sun et al., 2018).

3 5G/6G Systems and Other Communications Systems in Smart City with Research Challenges

3.1 5G/6G Systems for Smart Cities

The 5G network was designed with promise of providing eMBB (enhanced Mobile Broadband), URLLC (Ultra Reliable Low Latency Communications) and mMTC (massive Machine Type Communications) (ITU-R & Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-, 2020 2021). eMBB data rates of 0.1 Gbps are promised with very low latency, decreasing by a factor of 5 of <1 ms and enabling communications from machine-to-machine and IoT. The 6G system is offering even more throughput, almost zero latency and connects anything and everything (Zhao et al., 2020). For that to happen, the new system specification is required to provide uDB (ultra-fast device broadband), smMTC (smart massive machine type connection) and suRLLC (super ultra-Reliable Low Latency Communications) as depicted in Fig. 4. Connectivity is anticipated to reach peak data rates of 1000 Gbps for data intensity applications such VAR. Every other device in the network can experience a data rate of 1 Gbps which enables services and applications in smart cities to be realized. Device-to-device (D2D), Internet of Everything (IoE), vehicle-to-vehicle (V2V), and vehicle-to-everything (V2X) will be added to the massive machine type communications to offer a network for machine and people. With inclusion of AI in the devices and machines, the second major service will see smart massive machine type connection with a connection density of 10^7 devices/km^2. To have a connection always reliably to support smart cities, the network must be super ultra-reliable with very low latency and delay jitter. 6G promised to offer latency of 0.1 ms and delay jitter of 10^{-3} ms.

Research has commenced in the area of 6G communications systems with interesting new technologies that can enrich the concept of smart cities. Various comprehensive surveys in Zhao, et al. (2020); Zhang et al., 2020; Imoize et al., 2021; Akyildiz et al., 2020) have envisioned the following technologies as shown in Fig. 5. The following technologies will make 6G the enabling communications system for smart cities; artificial intelligence (AI),

Fig. 4 The evolution from 5G to 6G communications systems

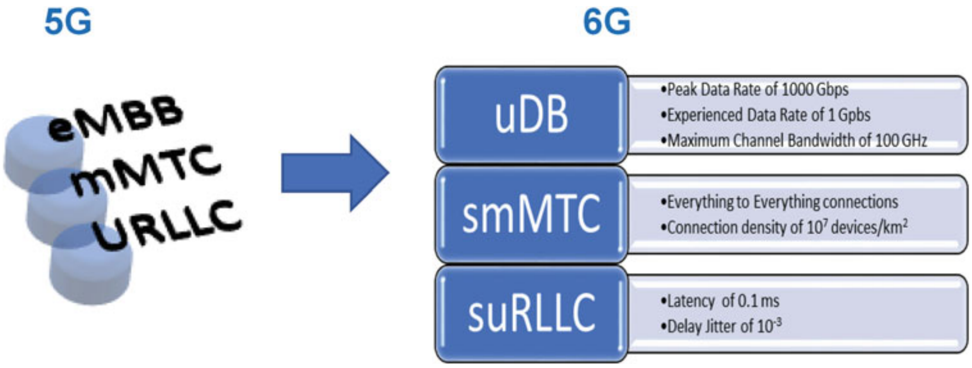
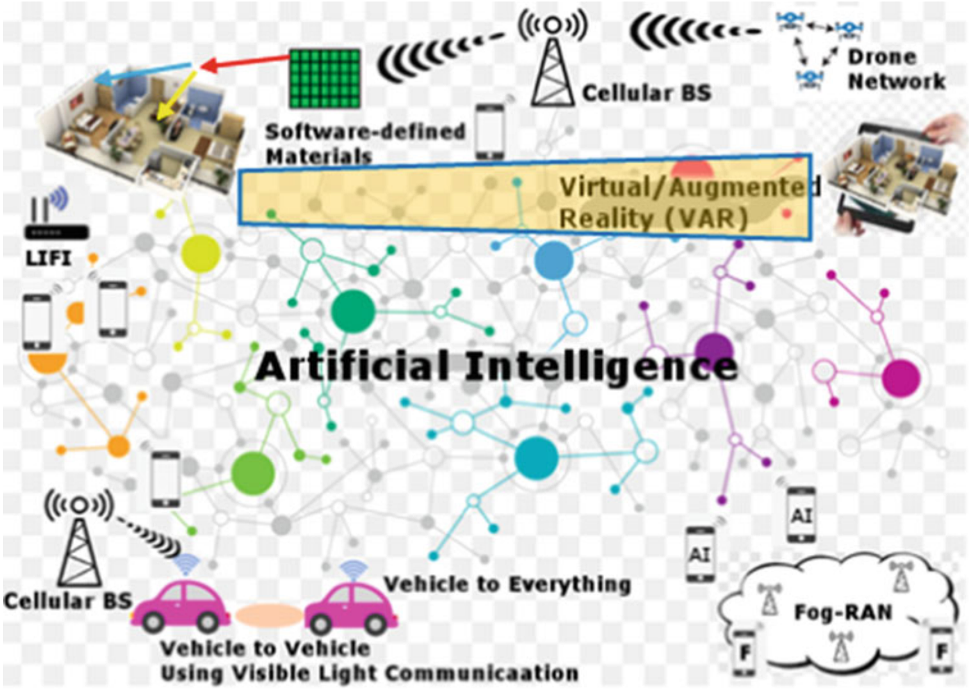


Fig. 5 What's possible with 6G?



AI – AI Enable Device; F – Fog User Equipment; Unlabeled – Smart Device

software-defined materials, virtual and augmented reality, ubiquitous network, index modulation and device-to-device communications.

Artificial Intelligence. In the middle of the communications network is the application of pervasive or collective AI to provide efficient management of the communications network. With the vision to connect everything connectable to the network, resource management for the massive heterogeneous connections will be too much for current technology. Also, the big data available will overpower the current supercomputers; however, AI tools such as machine learning (ML) are expected to analyze the data, learn from it and make better choices in the management of the network (Imoize, et al., 2021; Zhao, et al., 2020). Therefore, AI will be an integral part of 6G.

Software-Defined Materials. As the use of the macro-cell in current mobile network is incapable of providing the high availability for smart city connectivity, complementary technology is need. The application of an intelligent reflecting surface (IRS) on infrastructure by software-defined materials, is a good candidate to improve network connectivity by creating smart propagation paths for signal transmission (Liu et al., 2021). The IRS consists of an array of IRS units that can be individually controlled by a controller to change the signal characteristics as it reflects off the surface in the propagation direction as shown in Fig. 6 where a base station is communicating with a mobile user via the IRS. With the high user-density and large volume of data generated in a smart city, it is vital that the controller in this system be based on some form of AI (Liaskos et al., 2019). The software-defined materials contain meta-atoms that allow the currents on the surface of the materials to be manipulated. As the electromagnetic wave touches the surface as it propagates, the meta-atoms can modify the direction, power, frequency spectrum, polarity and phase of the wave (Liaskos et al., 2019). This feature allows the IRS to extend the coverage range as well as capacity of the communications link.

Virtual/augmented reality (VAR). The promise by the 6G network to have continuous connectivity with latency as low as 0.1 ms, provides the platform to have virtual and augmented reality (VAR) in smart cities. The application of VAR can be realized in tourism, navigation, education and disaster response to make the life of people easier and safer (Yagol et al., 2018). A tourist can use virtual reality to evaluate tour packages on offer to make informed choice on available services even before taking the tours. In comparison, in this present era, more tourists make their choices on tourist feedback which may not always be true or accurate. Thus, using virtual reality, tourists can be certain about the quality of service expected, that their security is assured and have instilled in themselves a peace of mind. Having a navigation system ensure that people, including tourists, can get the most out of their travels in the city, is most beneficial. Augmented reality can improve traveling within the smart city with the information about traffic, cab stops and even availability to help people make informed decision regarding their travel. Also, the methods in offering education to its people will improve with the use of VAR in the classroom. Finally, the use of VAR in offering first responders in an emergency makes rescue efforts efficient and offers peace of mind to people living in the smart city that their lives can be and are protected. The 6G system in smart cities empowers the city to offer a safe and peaceful environment for the people.

Ubiquitous network. In current mobile networks, we experience busty traffic, variable speed and frequent drops in network connectivity (Xiao, 2018). However, smart cities will thrive on a communications network that is always on. Therefore, new network access and connectivity methods are required to support reliable communications in smart cities. A ubiquitous network where any device which can make a network connection can become a connection node in the network to extend coverage and establish a link connection. By doing so, there will always be a path between two communicating devices within the network. These paths can be in space, in air, on the ground and even under the sea. In Fig. 5 we see the drone network in the air which can be used during an emergency when the normal network is disrupted. This can be coordinated from space using satellites. A redundant path to the emergency network can be through submarine cables if the terrestrial links are destroyed. Connectivity is established across any available means. Also, for traffic management, different media can be used to balance traffic and make the network efficient (Zhao et al., 2020). Thus, the ubiquitous network is another equally important technology to enhance communications in smart cities that is made possible with D2D communication.

Device-to-Device Communications. To implement VAR, the ubiquitous network, and Internet of Everything in smart cities would to some degree need the services offered by D2D communications. Also, AI through ML will be an

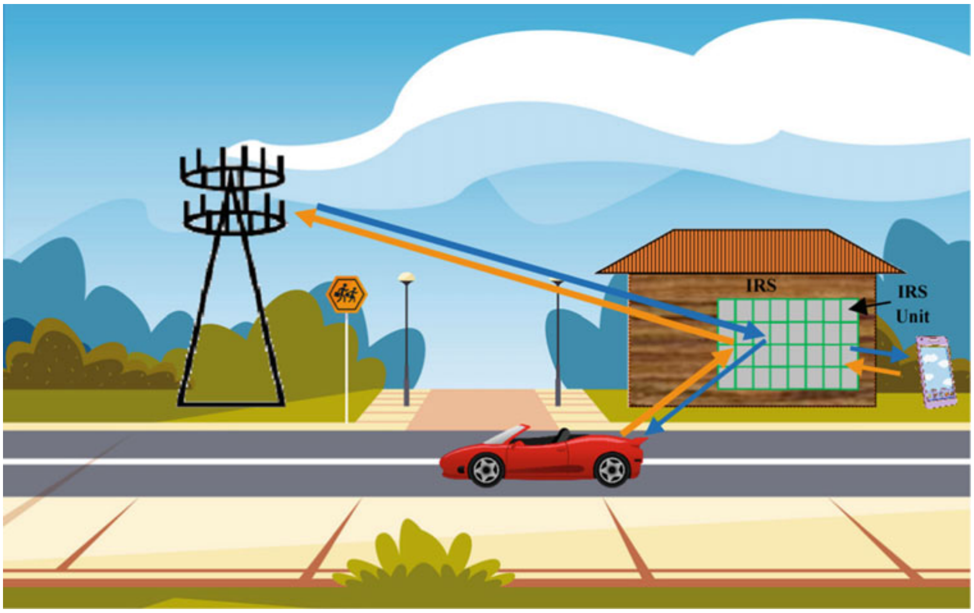


Fig. 6 Communicating through the intelligent reflecting surface (IRS)

integral part of the smart city communications network. D2D services will require mobile edge computing, network slicing and non-orthogonal multiple access cognitive networking to be effective (Zhang et al., 2020). Mobile edge computing will require some form of AI to manage the resources to be shared among all the devices that needed connectivity within the network edge supporting the smart cities (Imoize et al., 2021; Shahraki, 2021). The smart phones of today will become sensor nodes, speedometers, medical devices, educational tools, search and rescue first respondents' tools and much more. The application of AI will be implemented in the network core and edge to support network slicing. The dynamics environment in smart cities with every user device having heterogeneous latency and processing demands establishes the need for ML to perform adaptive network slicing to satisfy these demands (Nassar & Yilmaz, 2020; Singh et al., 2020; Zhou et al., 2020).

3.2 Other Communications Networks

In the effort for increased speed in the backhaul, fiber networks, microwave networks, and satellite communications (SATCOM) networks will also be utilized to fully implement ubiquitous networks to support smart cities' applications and services.

Satellite networks offers a wider footprint and coverage area than any mobile base station. Smart antennas offer increased channel capacity and coverage for SATCOM on-the-move (STOM) (Luo & Gao, 2017). Thus, for smart city application, STOM would replace the macro-cells at the outer edges for unreached enabling connectivity to be established in space to ground. However, IoT in smart cities cannot tolerate the high latency and delay when using satellite communications. The situation is further complicated with high mobility. The movement changes the propagation environment thus disrupting the communications link and reducing link reliability. Also, shadowing (Hornillo-Mellado et al., 2020) is an issue with satellite communications in high rise areas but with the use of IRS, the effects of shadowing can be contained. SATCOM is also a transmission medium in implementing full ubiquitous networks from smart cities in conjunction with fiber and terrestrial communications.

Terrestrial backhaul networks have been the backbone of the communications networks for years. Despite the low speed and minimum coverage area, the network speed is sufficient for IoT connectivity in smart cities. Alternatively, terrestrial links can be used to complement the wider covering non-terrestrial link as a redundant path or load balancing in the network to improve latency and reliability (Wang et al., 2020). Therefore, terrestrial communications networks will also form part of the communications networks for smart cities mainly for IoT application.

3.3 Research Challenges for Smart Cities

There is much to do in preparing the communications networks to support the known and unknown requirements for smart cities. The known challenges that pose a challenge for smart cities include cybersecurity, handling of the big data to be collected (Akyildiz et al., 2020; Georgescu & Popescul, 2016) and developing effective green energy systems for mobile devices and sensor.

Cybersecurity. The threat to cybersecurity in smart cities is amplified with the availability of network connectivity and people conducting business on the go especially on public transport. Reference (Rubin, 2011) presented some intriguing work by researchers on the possibility of hacking into vehicles, two-way radios and private accounts. It was shown that with the appropriate equipment and knowledge it is possible to take control of a vehicle through one of the many communications systems available for the comfort of the passengers. In smart cities where IoE is an application, the availability of capturing private information will be much easier. Therefore, more awareness and policy formation to safeguard personal information and people in smart cities is much needed. Further to cyber security is the need to handle data securely.

Big Data. The handling of the extensive data generated by every connected thing in smart cities also offers some challenges. The first is the safe handling of personal data to ensure that the privacy of people is protected. The choice of storage will determine the legality of the location and speed in which this data is accessed. If the data is stored further away from the user, there will be delays in the network which thus reduces the overall performance of the network (Georgescu & Popescul, 2016) as in the case of cyber-physical systems such as autonomous vehicles and unmanned aerial vehicles (UAV) (Akyildiz et al., 2020) and analysis …

Power Consumption. With the use of pervasive AI in the core and AI enabled devices on the edge the power requirement for mobile devices will be a challenge in smart cities. However, by clustering the AI enabled smart devices the computing burden can be shared with edge devices on the cooperated network and thus power consumption is minimized (Zhang et al., 2020). The mechanisms and techniques on how to achieve the load sharing is unknown and is an open research question.

4 A Fast and Light ANN Enabled Antenna for Internet of Everything for a Smart City

High mobility would be the major complementary and enabling concept with smart cities (Obaidat & Nicopolitidis, 2016). Prior to 5G networks, mobility was mostly by humans. Beyond 5G with the implementation of vehicle to everything, V2X, machine-to-machine, M2M, and device-to-device communications, there is a need for a new radio interface. The new radio interface must be able to support the varying need of all applications in implementing their services. A vital requirement for the new radio interface would be sensing the direction of arrival (DoA) and adapting the antenna parameters to track the mobile equipment. Since the mobile equipment is always on the move, real-time tracking in three dimensions is important (Obaidat & Nicopolitidis, 2016). In addition to application need, there are the security threats and variabilities to embrace with open medium and massive data exchanges in networks beyond 5G (Silva & Flauzino, 2016). These two requirements can be implemented in the physical layer with a new radio. This section discusses the artificial neural network (ANN) antenna for smart cities, beginning with an overview of ANN antennas, and their application in smart physical safety and security, smart education, smart energy, smart transportation and smart sensing of human activity. This section concludes with a discussion of the ANN driven antenna with which to support the applications mentioned earlier.

The antenna systems for 5G networks and beyond have to be smart array antennas with multiple input multiple output (MIMO) and it is predicted that the number of smart antenna would rise by 74% by the year 2026 (Markets & R.a., 2021). The key requirement remains that a new radio interface would be necessary to provide mobility for many new and enhanced applications envisioned to support smart cities through IoT (Cicirelli et al., 2019; Markets & R.a., 2021; Sun et al., 2018). An effective mobility function is dependent on a reliable and secure communications link. A reliable MIMO communications link is a secured, high availability link with less interference. In Reference (Wang et al., 2012) the authors demonstrated the reliability of a MIMO link against malicious attracts or interference and link failures with space–time block coding. The reliability of the MIMO link is improved with the increased number of elements (Senthilkumar et al., 2021; Wang et al., 2012). However, this also increased computation and power consummation. This approach is not applicable to mobile devices. Therefore, we propose that fast and simple MIMO antenna with tracking be employed.

4.1 ANN Antenna Model

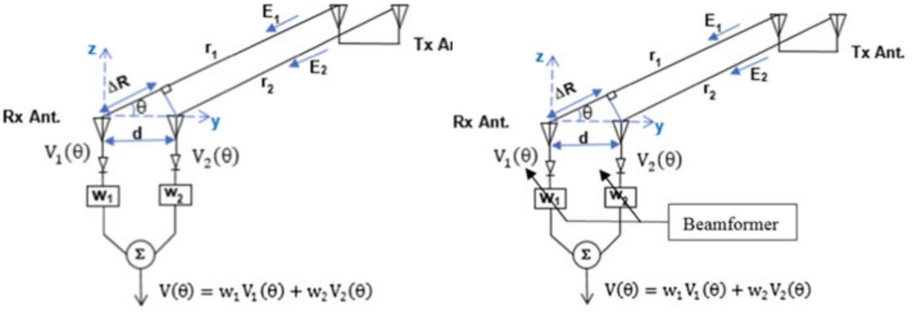
The smart antenna and an ANN enabled smart antenna are shown in Fig. 7. In Fig. 7a we show the analytical smart antenna based on an array factor of a 2 × 2 MIMO antenna system. As shown in Fig. 8a and Fig. 8b the smart antenna can form nulls in the direction of the interfering signal and maximum beam in a desired look angle respectively. The weights, w_1 and w_2, were calculated numerically and used to plot the array factor. However, in Fig. 7b the weights are determined using an ANN based beamformer in Senthilkumar et al., (2021). The operation of the ANN enabled smart antenna is discussed in the next section with three cases; case 1 involves beamforming, case 1 demonstrates null forming and case 3 demonstrates the tracking ability of ANN enabled smart antenna.

The output of the summer is determined to be

$$V(\theta) = w_1 e^{(j\delta_1)} V_0 e^{(-jkr_1)} + w_2 e^{(j\delta_2)} V_0 e^{(-jk(r1\,kd\,\cos\theta))} \quad (1)$$

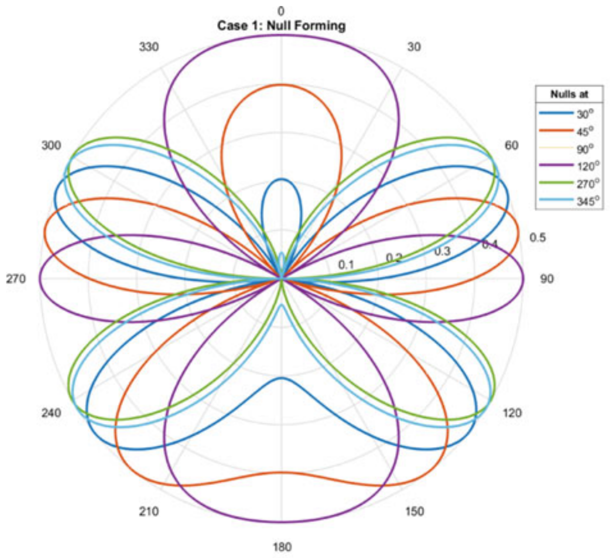
where w_1 and w_2 are the weights, δ_1 and δ_2 are the phase and θ being the angle of arrival of the incident wave. The analytical model determines the weights using numerical methods in MATLAB. The case illustrated in Fig. 8 is plot of the normalized array factor from (1) to be:

$$AF_N = AF/2 = \sin(\gamma/2) \quad (2)$$

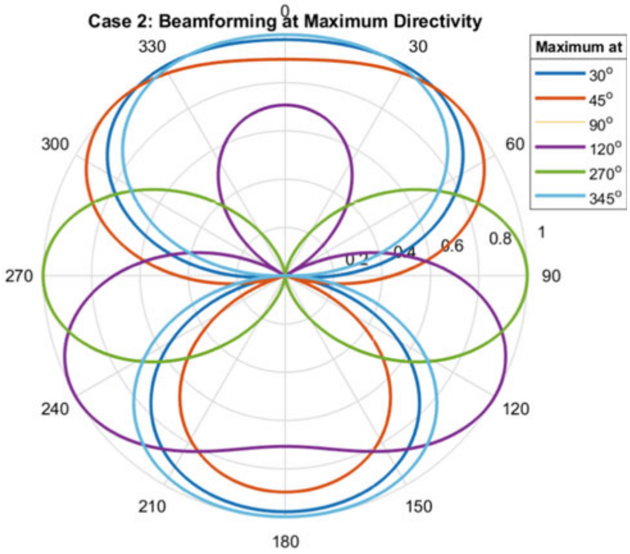


a) 2 x 2 MIMO Smart Antenna [31]   b) ANN Enabled 2 x 2 MIMO Smart Antenna

Fig. 7 **a** Smart antenna model and **b** ANN enabled smart antenna



a) Forming Nulls in the Direction of the Interfering Source



b) Forming Beams in the Desired Direction

Fig. 8 Analytical smart antenna null and beam forming ability (Kunsei et al., 2021)

with $\gamma = kd(\cos\theta - \cos\theta_i)$ and θ_I being the direction of interference and

$$AF_N = AF/2 = \cos(\gamma/2) \tag{3}$$

with $\gamma = kd(\cos\theta - \cos\theta_m)$ and θ_m as direction of maximum beam.

The single perceptron ANN use in Fig. 7b is configured with initial weights of −0.001 for w_1 and w_2 with a bias of 0.1. The learning rate was taken to be 0.0025. The training data is both −0.001 for both inputs. The performance of the ANN model is discussed in Sects. 4.2 and 4.3 in implementing the tracking algorithm and compared with the analytical model.

4.2 Localization with ANN Enabled Antenna

A step prior to beamforming is to determine the look angle for the antenna to use in the beamformer to form either a null or a beam. It is established that smart antennas can be used for localization based on the angle of arrival (AOA) (Giorgetti et al., 2009). The process usually works off some known reference. In this work we are working off the radiation pattern within the coverage area of the base station.

The concept is illustrated in.

Figure 9, where a beam from the tower is covering some area. The normalized power is maximum with power level of 1 at the tip edge of the radiation pattern. Any movement away from that point would see a drop in the signal power as indicated in the longitudinal centerline. The spine on the pattern indicates that the power level is the same as the spherical distance from the base of the tower would be if there is no interference. Thus, the location of the mobile transceiver can be determined from the signal strength in the beam pair. As the mobile transceiver moves, the power level also changes. Figure 10 shows the change in the power level and the tracking implemented in the analytical beamformer (Kunsei et al., 2021) compared with the SNWOM (Senthilkumar et al., 2021). As shown in Fig. 10, the analytical beamformer agrees with the ANN beamformer despite the very small movement.

The benefit of the proposed tracking methods would reduce the overhead needed to find the beam for user communication, reduce latency and reduce straddling loss (Asplund et al., 2020). If the beam is wide, there will be less handoff taking place in the mobile network. In smart cities where a reliable communications link for device-to-device, machine-to-machine or humans to everything is required, tracking becomes vital.

Other localization techniques include the timing, signal strength, signal pattern matching, directionality, and using Infra-Red (IR) (Bulusu et al., 2000). Most of these methods would require additional instruments to act as reference points for comparison. These reference points would need wired connectivity to operate. Thus, as the network grows the system does not scale well. Directionality methods have

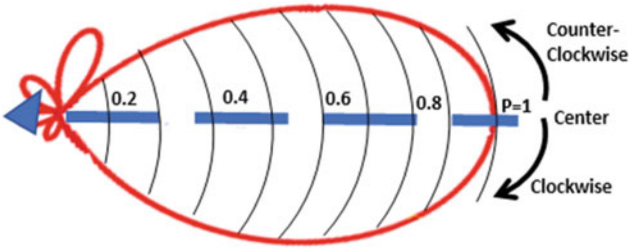


Fig. 9 Beam coverage area showing normalized power levels for tracking

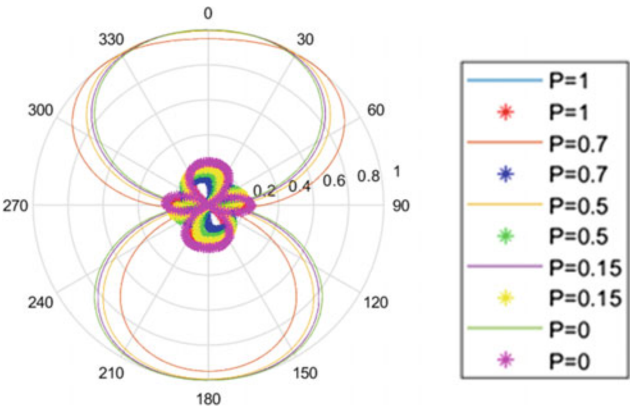


Fig. 10 Tracking the power level using analytical beamformer and ANN beamformer, SNWOM with Sigmoid as the activation function

drawbacks in requiring a complex array and incompatible scalability issues dealing with a large number of nodes as receivers increase. Thus, a less complex and fast method of tracking is necessary for the smart city applications.

4.3 Beamforming with SNWOM

The ANN enabled smart antenna with 2 elements in Fig. 8 with the configuration described in Sect. 4.1 is used to demonstrate beamforming at angle of departure of 60 ° and 150 °. The desired function is plotted in blue while the ANN enabled smart antenna's is the red plot. It was shown in Reference (Senthilkumar et al., 2021) that the shape of the radiation pattern would improve with more elements with a non-uniform linear array. Therefore, the radiation pattern does not agree with the desired pattern, however the ability to form a beam in the desired direction is demonstrated to confirm the concept. In this case, the activation function used is the sigmoid function (Fig. 11).

In Fig. 12, we compare the two activation functions; the sigmoid and the squash activation functions. We note that the squash activation function shows a better magnitude response compared to the sigmoid function. Thus, it does confirm the hypothesis that there must be a better activation function for certain applications. However, the difference between the desired output and either activation function is quite high. This may be improved by adding more elements and changing the geometry of the array antenna as shown in Fig. 13.

4.4 Tracking with ANN Enabled Smart Antenna

The challenge with tracking the mobile transceiver is usually a two-fold approach. The first approach is to determine the DoA using either the MUltiple SIgnal Classification (MUSIC) Technique or the Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) (Macharia et al., 2019). Though these two techniques are electronical implemented, they are still computationally intensive for the limited power in the mobile devices. Once the DoA is established, it becomes the look angle for the beamformer algorithm to enhance the desired signal coming from either a known or unknown direction and to null any interfering signals (Liu & Weiss, 2010). We propose a method to manage the beam pair between the base station and the mobile transceiver by sensing the received signal strength in

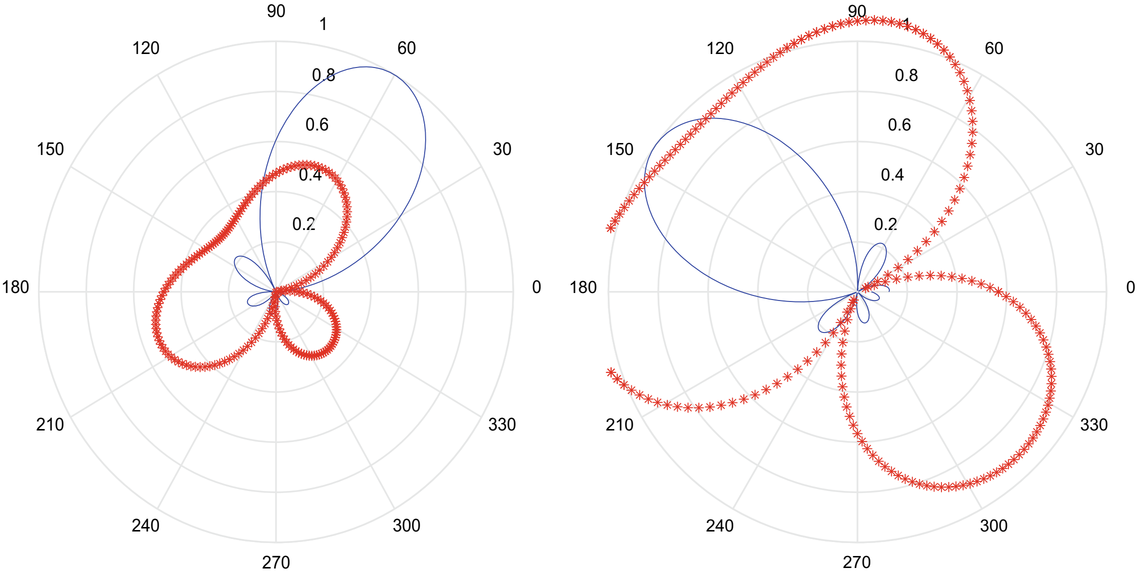


Fig. 11 Beamforming with SNWOM in the look angles of 60 ° and 150 ° with the bias constant with the sigmoid activation function

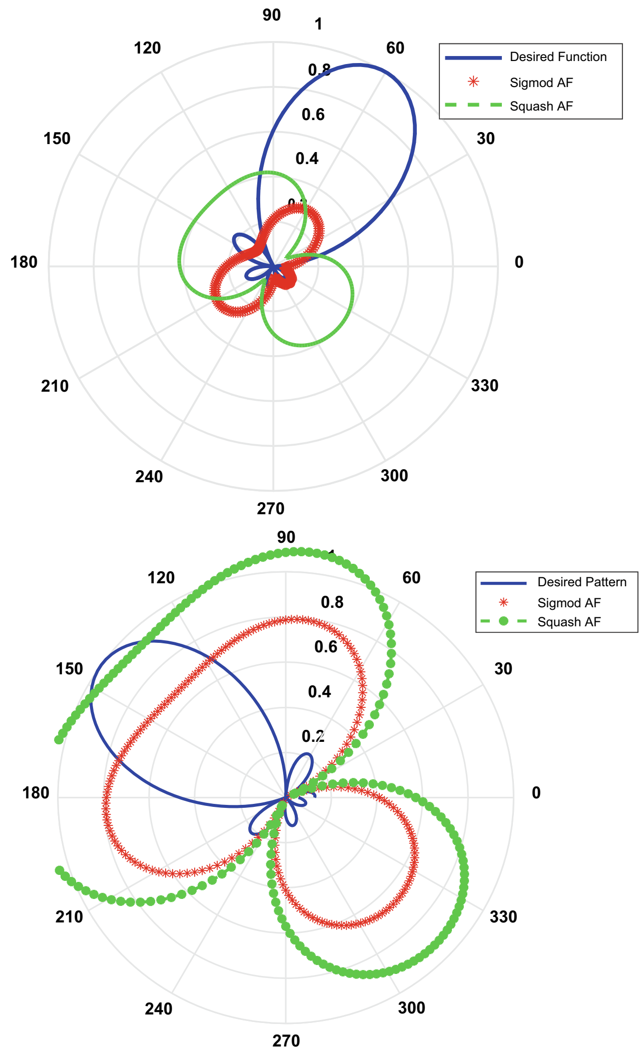


Fig. 12 Beamforming with SNWOM in look angles of 60 ° and 150 ° comparing two activation functions with the bias constant

comparison to the radiation pattern of the transmitting base station (Kunsei et al., 2021) as discussed in Sect. 4.2.

Tracking of mobile users can be achieved in several ways. However, the existing methods are computational intensive (Caylar et al., 2006). Thus, in this section we develop a simple, yet accurate and less computational need by using the antenna radiation. However, since the coverage space is extremely large, ANN is employed to determine exact angle of arrival.

Figure 14 illustrates the radiation pattern of sectorial antenna. Figure 14a shows the tilted beam toward the ground to provide coverage. Figure 14b is the approximate antenna pattern aligned on the ground on the x–y axis. The reference is taken from the x axis; thus, the maximum is about 90 °. To track user using the radiation pattern, the power level is normalized by the maximum power. Thus, the normalized power of 1 is directed to 90 °.

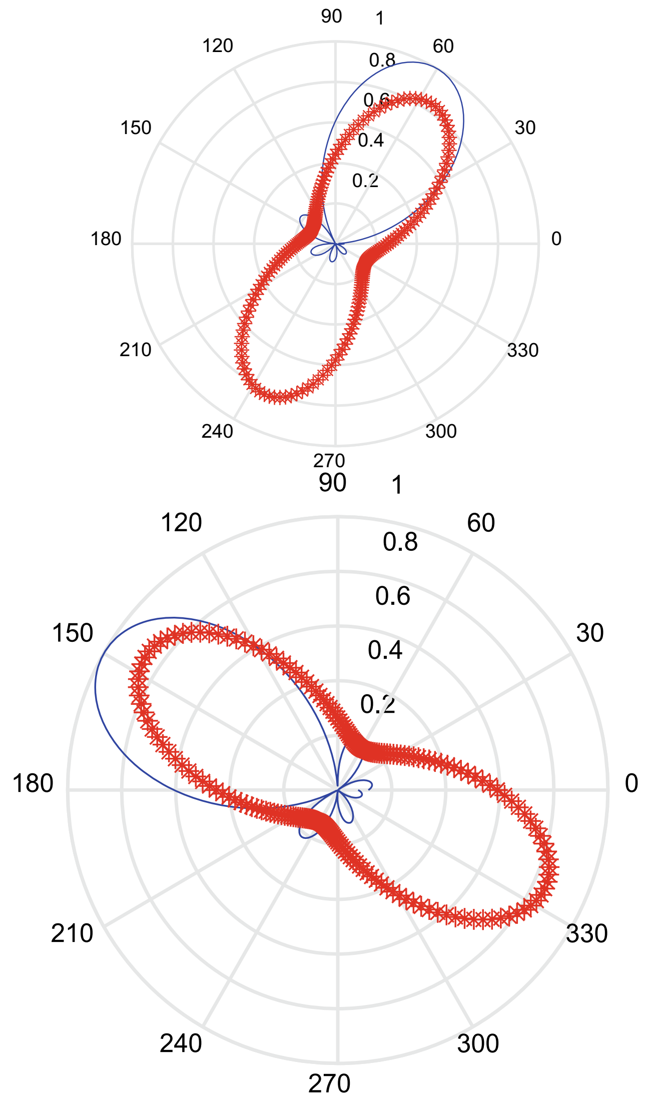


Fig. 13 Reproducing with 4 elements for look angles of 60 ° and 150 °

The signal strength will determine the radial distance from the origin or pole. In terms of antenna pattern measurements, the power along a radial distance will be the same level. Thus, for fixed radial distance, theta angle for the each of the quadrant will have the same magnitude with different direction as indicated in Table 1.

The power level in Table 1 is determined from Kunsei et al. (2021).

$$\mathrm{p} = \cos(\mathrm{kd}(\cos\theta - \cos\theta_{\mathrm{m}})/2) \tag{4}$$

where theta, θ, is the angle of arrival and can be taken as new angle based on the power level. The power level for each of the quadrant with the same radial distance is the same as

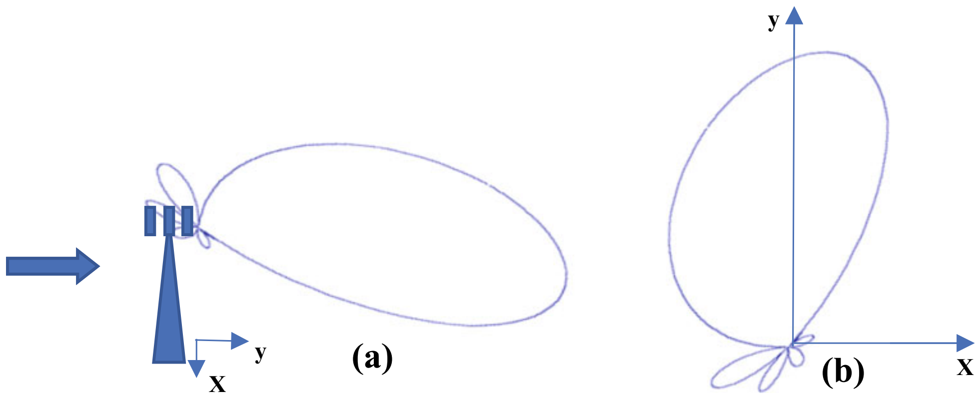


Fig. 14 Radiation Pattern in the Propagation Environment

Table 1 Comparison of directional of arrival from propagation environment with radiation pattern

x	*y*	Theta from mobile unit position	Power level from Theta of mobile unit position	Theta from power level	Difference
2	4	63.4	0.8406	41.3	22.1
2	−4	−63.4	0.8406	41.3	22.1
−2	4	−63.4	0.8406	41.3	22.1
−2	−4	63.4	0.8406	41.3	22.1
4	6	56.3	0.7858	50.8	5.5
100	200	63.4	0.8046	41.3	22.1
−4	6	−56.3	0.7585	50.8	5.5
−100	200	−63.4	0.8046	41.3	22.1
10,000	10,000	45	0.8839	13.25	31.75
–10,000	10,000	−45	0.8839	13.25	31.75

shown in the Table 1. We assume that sectorial antenna is 180 ° as shown in Fig. 14.

The new angle based on the power level can be calculated from (4) as:

$$\theta_{\rm n} = \cos^{-1}\left[\left(2 * \cos^{-1}({\rm p})\right)/({\rm kd} + \cos\theta_{\rm m})\right] \tag{5}$$

Equation (5) was used to calculate the new angle is recorded in Table 1. If the coordinates and the antenna pattern are aligned the beamforming angle determined from the geographical *x*, *y* coordinates should equal the new angle determined from the normalized power level of the radiation pattern of the antenna. It is evident that there is a mismatch in the theta values as shown in the last column in Table 1. Thus, a correction variable is needed in addition to the shifting variable, β, to indicate the direction of the mobile unit.

For 4G system the normalized power level of 1 is equal to −75 dBm. The maximum range is more than 10 km when the operating frequency is 1800 MHz and lower with the transmit power set to 20 W, transmit and receive antenna gains of 1 as shown in Fig. 15. The choice of operating frequency will determine the range of the antenna pattern. Therefore, the coverage area at 1800 MHz will be at least 10 km per sectorial antenna. The coverage space above about 20 × 20 km area from the pole is a huge area to determine all possible mobile station location and the direction of movement. However, it does show that the resolution of the tracking angle would be high and easier to determine.

If we use the contour of field strength of −79 dBm as an illustration, then at the boresight at x = 0, the normalized power would be 1 at about 23 km from the antenna as indicated by an A in Fig. 16. As the mobile user moves away from the maximum beam the power level will be less than 1 as illustrated in Table 1. In this case, the angle of maximum strength is 90 °. At 10 km, calculations in Table 1 shows that the angle is 45 ° with power level of 0.8839. Using the power level relationship in (4) we determine the new theta angle the beamformer to direct the main lobe. Figure 16 shows the radiation pattern with the positional coordinates from Table 1 when *x* and *y* are 10 km. The power level has reduced by 1 dBm which implies that the normalized power level is 0.99. Therefore, the new angle of the mobile unit in clockwise direction at position B is:

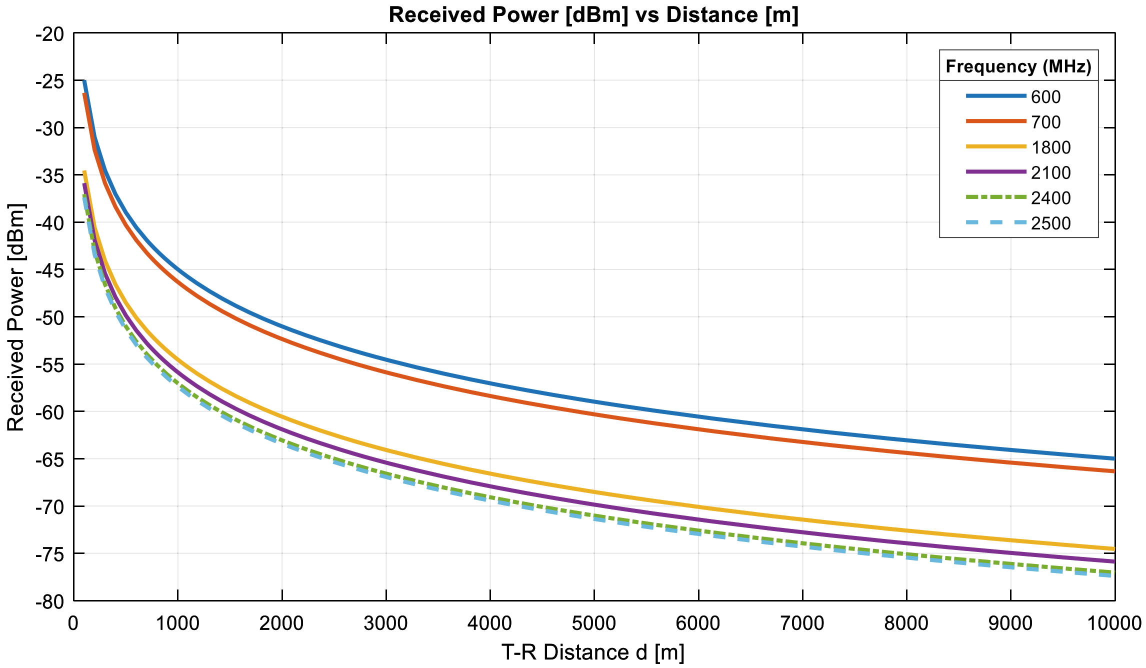


Fig. 15 Comparing received power against distance for a 4G base station operating at 600 MHz, 700 MHz, 1.8 GHz, 2.1 GHz, 2.4 GHz, and 2.5 GHz with unity antenna gains and 20 Watts transmit power

$$\theta_{newcw} = \theta_{newfromposition} - \theta_{newfrompower} \qquad (6)$$

when the mobile unit is moving in the counter clockwise direction, the new angle at position C in Fig. 16 is.

$$\theta_{newccw} = \theta_{max} + \theta_{newfromposition} - \theta_{newfrompower} \qquad (7)$$

The reference point is taken to be $x = 0$. Thus for a clockwise movement of the mobile station, the new angle should be less than the previous maximum angle, $\theta_{newcw} <$ $_{max}$, as shown in (6). Following on the counter clockwise direction, the new angle should be more than previous maximum angle, $\theta_{newccw} > \theta_{max}$ as shown in (7).

4.5 Application of ANN Smart Antennas in Smart Cities

4.5.1 Smart Energy with ANN Enabled Smart Antennas

Smart cities will see integration of renewable energy in smart homes and industries. In developing countries where the smart city concept is extended to rural areas, renewable sources may be the only possibilities in the smart village setting (Kempener et al., 2015). In this setting the monitoring and control of hybrid sources of renewable energy become vital for the sustainability of the energy system. By making the renewable energy system smart, the system is sustained with technologies such as by demand response (DR), smart inverters, renewable distribution automation (DA), virtual power plants and microgrids (Kempener et al., 2015). These smart technologies enable the renewable energy system to be flexible, responsive and intelligent. However, this is only possible with a reliable and intelligent wireless communications system.

For example, in a community depending on the micro-hydro renewable system, the regulator of the governor for the generator can be controlled to match the load on demand response. The smart antenna with tracking can establish a beam pair with the controller circuit and with the smart meters at the home. Whenever the load changes, the controller can adjust the speed on the generator to produce the required power to match the load.

Another example involves the monitoring and control of the generation source in a hybrid of hydro-solar renewable system as in Reference (Urame & Hoole, 2020). The system is equipped with a smart controller for monitoring the charge on the storage capacity between two renewable sources as illustrated in Fig. 17. To ensure that the system can be monitored remotely a smart antenna is installed in the controller to communicate with any mobile device via the mobile network and controlled anywhere in the world. In addition, environmental sensors installed in the vicinity of the renewable energy system installation can be monitored by the same smart antenna with the dedicated beam pair for remote sensing and monitoring of the environment.

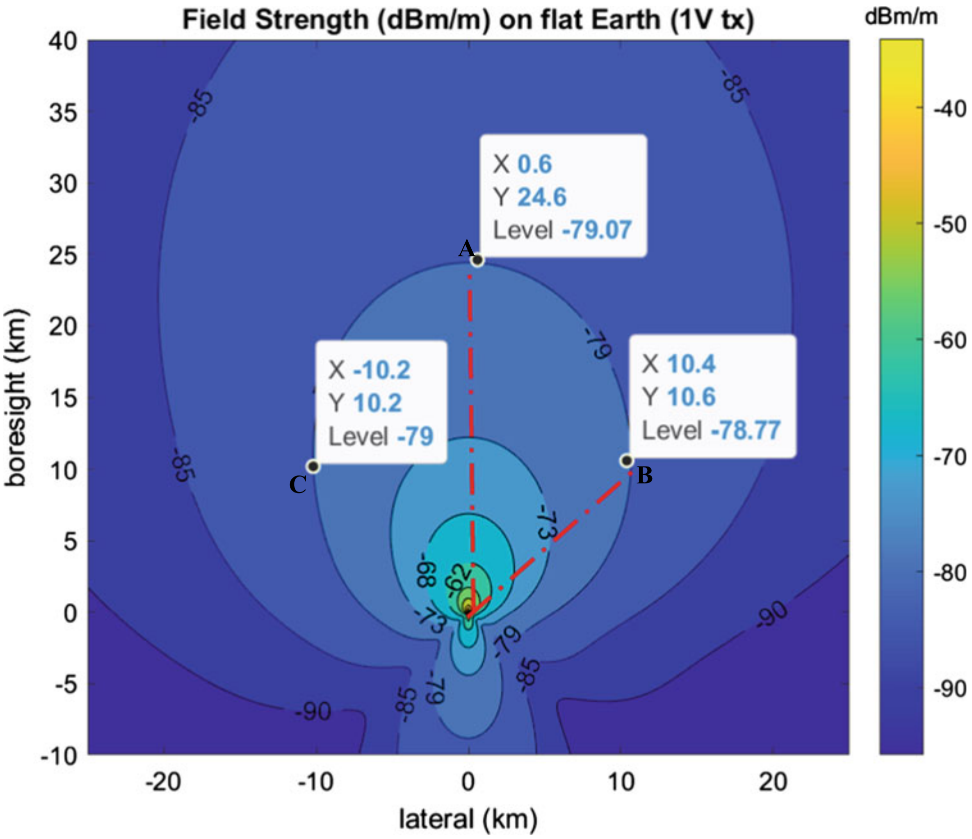


Fig. 16 Field strength of a directional antenna at 1800 MHz with 1 V at transmitting voltage

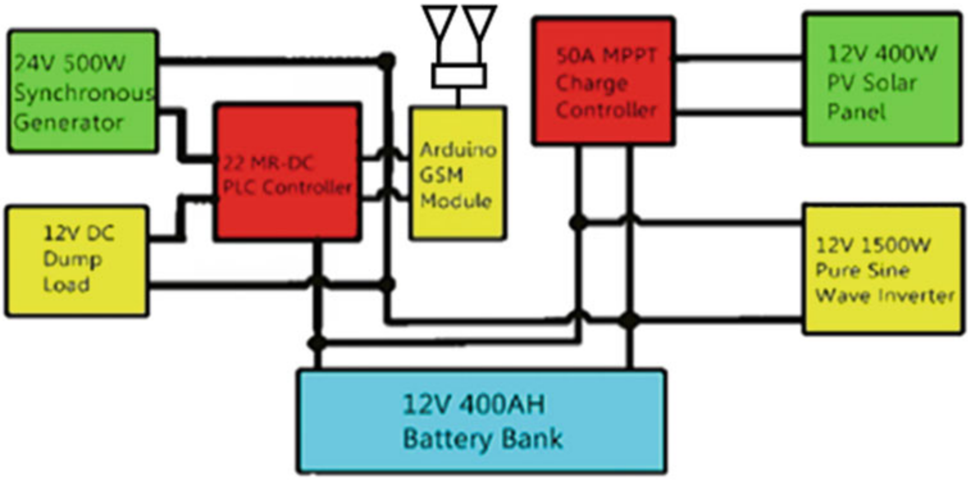


Fig. 17 Smart antenna enabled controller for monitoring and control

In the smart grid in the urban areas, the smart antenna can be used to monitor the health of the components in a substation or distribution network. In the substation, the health of the circuit breakers is the difference between a long downtime and short downtime, or the difference between a less reliable or reliable power system. In current wireless systems, conventional antenna systems are used to connect all circuit breakers to the control room. The data exchange can be large and informative. However, with the use of a smart antenna, the system can do more than just exchange information between nodes. Some processing could be performed on the data in the antenna before alerts or records could be updated at the end of the data processing. A circuit breaker time in operation either in the mechanical or electrical system can be measured from the uptime and downtime of the component as the beam link is dedicated between the transmitting and receiving antennas. An intermittent break in uptime may indicate the health of the circuit breaker and an alert can be generated by the monitoring system for maintenance to be scheduled, thus reducing downtime and improving system reliability (Mathur et al., 2018).

4.5.2 Smart Transportation with ANN Enabled Smart Antennas

Transportation systems involve high mobility with varying speeds. Implementing a smart transportation system will depend entirely on a wireless communications system for connectivity. The reliability of the wireless connection depends on the antenna system for the selected application. In vehicle to vehicle (V2V) or car to car (C2C) communications, omnidirectional antennas are applicable because of the need to have coverage all around the vehicle or car for short distances. However, for applications such as traffic and fleet monitoring and control, integrated public transportation, and real-time services for drivers and passengers require an antenna system with the ability to track the mobile unit, perform distance coverage and mitigate multipath interference.

Figure 18 shows a typical smart transportation service and application with the relevant communications requirements. In Fig. 15a the concept of providing real-time messages for drivers is illustrated with the sending of a warning message alerting nearby or approaching drivers of the accident ahead in the traffic to safeguard them and their passengers. The use of an ANN beamforming antenna would maintain the beam pair between the vehicles or with base stations. A warning message can be delivered in real time and with low latency. Also, the link can be so secured that no hoax or bogus messages should be delivered through the system.

Furthermore, to implementing V2V communication is as shown in Fig. 18b, which illustrates a 2 element (blue dots) ANN smart antenna It is highly applicable when a narrow or variable sized beam width and a highly directed beam is required to establish a reliable communication link all around the vehicle. In a multipath environment where communications links are established based only on signal strength, the reliability of the link is much lower because of the continuous change in the received signal strength as the distance between the vehicles changes due to acceleration and deceleration.

Another application in Fig. 18b can be the implementation of multiple-input-multiple-output (MIMO) in V2V communications. MIMO antenna systems are renowned for exploiting multipath propagation in improving signal quality and capacity through diversity gain. However, the computational and power requirements may be an issue with compact vehicles. Alternatively, an ANN smart antenna with beamforming at millimeter wave frequencies can offer a reliable link with high capacity with stable performance as shown in Fig. 19.

By maintaining the distance between the antenna elements, the performance of the antenna is maintained when the power levels of the radiation pattern are used to estimate the location of the mobile user. The shape of the beam can be improved with more elements with nonlinear array configuration.

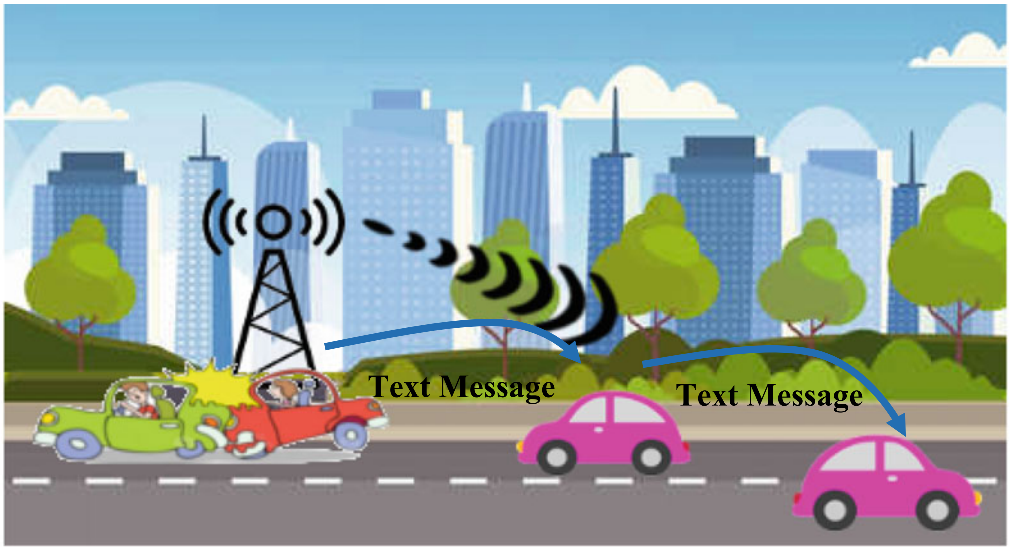
4.5.3 Sensing Human Activity with ANN Enabled Smart Antennas

The final case that may benefit from an ANN smart antenna is sensing human activity. The objective of knowing human mobility is to gain insights that can be used to implement efficiently managed human mobility in smart cities (Semanjski & Gautama, 2016). The process of acquiring the need to form the insights is usually manual, tedious and time consuming. Also, the records may not be complete and correct due to human incapability to remember every detail of their movement unless recorded on paper. With the widespread use of smart mobile phones with adequate mobile applications to track and store human activity, sensing human activity is much more exciting and accurate. Capturing the GPS data, information about the movement within a specified time frame can be obtained. Also, real-time location of the mobile device can be obtained through GPS tracking or tracking by an ANN enabled smart antenna.

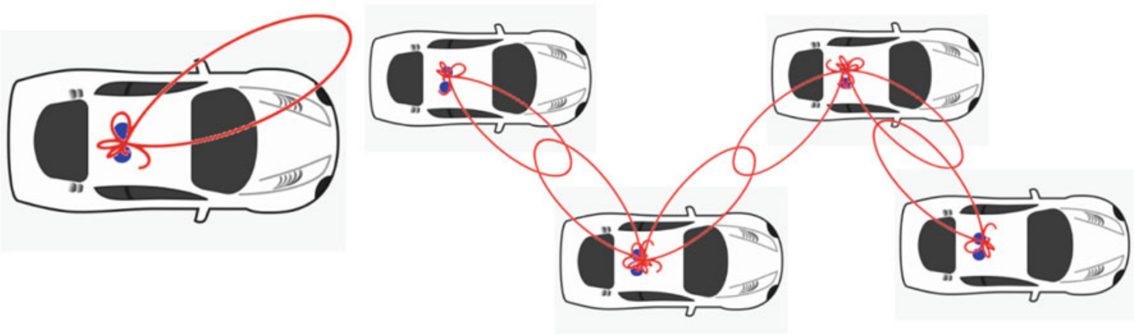
Location-enabled devices have been used in tracking vehicles but have relied on the global navigation satellite system (GNSS). A special electronic device is designed to communicate with the satellites to determine their location with very high precision. To track human mobility, one must carry the tracking device if a mobile phone is not enabled to communicate with the GNSS. However, with an ANN enabled smart antenna, the mobile radio system is all that is needed to ensure that tracking within a coverage area is achieved with high precision as discussed in Sect. 4.2. The tracking of a human in the case of an emergency is possible with this smart antenna. Also, the tracking of individuals in sporting areas, parks, forests, schools and neighborhoods is now possible with an ANN enabled smart antenna.

An added benefit of using an ANN smart antenna in human sensing with location-enabled devices is in implementing active or interactive tracking (Semanjski & Gautama, 2016). With the use of machine learning in the specialized mobile app (Developer, 2019) the smart antenna can be further tuned for other functions thus adding more features is a simple software enabled without the need for new hardware.

The challenge of sensing and tracking human activity is illustrated in Fig. 20 where two instances of human activity has been predicted in the space of 50 × 50 m^2 area. At the center of the area we have base stations, as illustrated by the red dot. The green cells in the illustration indicates the



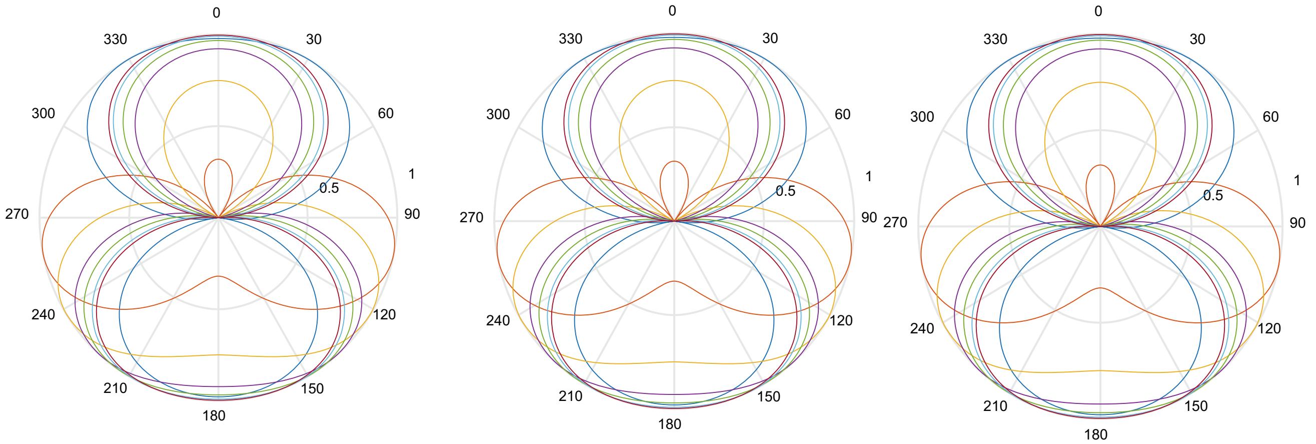
a) A Warning Message System



b) Smart Antenna: Vehicle-to-Vehicle

c) Vehicle to Vehicle using a Smart Antenna with multiple beams.

Fig. 18 Typical services and application for smart transportation. **a** Real-time messaging of traffic incident, **b** Antenna requirement for vehicle-to-vehicle (V2V) or vehicle to everything (V2X) communication, **c** V2V communication using a smart antenna on a road



(a) (b) (c)

Fig. 19 Stability plots for case 5 for three different frequencies, **a** 6 GHz, **b** 30 GHZ and **c** 60 GHz in Kunsei et al. (2021)

position of small cells which may be mobile devices that is being moved about by the movement of the human owners. It is anticipated that these small cells would change position more frequently. The challenge of sensing and tracking becomes more problematic when power efficiency is also a concern. A simple and energy efficient tracking method with the aid of ANN as discussed in Sect. 4.4 offers some hope for a truly mobile yet connected network in smart city for 5G networks and beyond.

A more robust algorithm would also predict the location of small cells and decide where to participate as a small cell as the location changes. As shown in the Fig. 20 some cells make be too close to the base station that it disqualifies to act as a small cell. However, the same mobile may again qualify should it move to another location. By using less but high quality set of data, the ANN smart antenna can perform the sensing with improved accuracy with less power which is a concern in mobile devices.

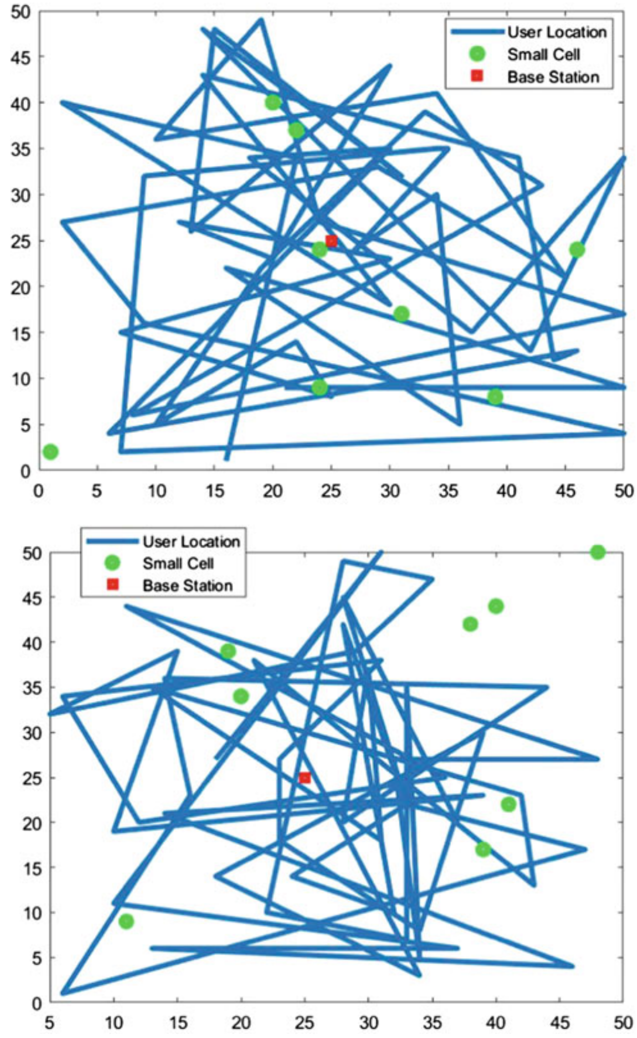


Fig. 20 Human movement in a 50 × 50 m area

5 Summary

This chapter addressed a vital component in the quest to make cities smart. Smart cities rely on data from everything and anything that offers some service to make the city safer, conducive for living and adaptable to enhance the livelihood of its citizens to learn from past experience, make informed decisions today and serve the citizens better tomorrow. It was argued that for a smart city to progress forward, it must not only have a reliable communications system but also an intelligent communications system. An optical fiber communications system is highly suited for backhaul networks with their high bandwidth and throughput. Therefore, wireless communications would be the widely deployed systems of choice in smart cities. Wireless communications systems include terrestrial microwave, Wi-Fi, RFID, Bluetooth, 5G and 6G networks.

Terrestrial microwave links are easy deploy on a short-term basis but are not enough for high intensity bandwidth applications such as gaming and VAR. Thus, it is not widely used in smart cities. For short range communication, Wi-Fi, RFID and Bluetooth are employed in small cell communications. These are used in service organizations that require payment via smart wallet or some other means while requiring network connectivity.

5G and 6G network characteristics offer super enhanced mobile broadband speeds that are required to support the new applications of smart cities such as virtual/augmented reality, V2V, D2D and M2M. In addition to speed, the 6G network offers extremely low latency to support critical applications such VAR and an emergency response team. Finally, the massive number of devices requiring connectivity in smart cities demands that any network should be reliable and intelligent.

The massive connectivity requires network management so that the established protocols and standards are not enough to handle the new and numerous connections. Thus, the core of the network must be intelligent. The specific form of AI to be applied in any level of the intelligent communications network depends on the function or service required. Furthermore, the edge of the network can be made intelligent by having edge devices that are AI enabled. However, some edge devices may not be intelligent as expected due to hardware limitations. An approach at the edge to make communication intelligent is the development and employment of AI enabled smart antennas.

We demonstrated in Sect. 4, a fast and low resource demanding ANN antenna that is capable of localizing and tracking the desired user with a narrow beamform. The application of the ANN enabled smart antenna is discussed in the provisioning of a smart energy system with monitoring and alerting in a digital distribution substation. The second application involves the support of an intelligent system with V2V communications. Finally, the vital function of sensing human activity is given the opportunity to use the tracking features to ANN enabled smart antennas to sense data for the planning and maintenance of public facilities. In all three applications, we note the relief to current manual techniques and burdens on humans when the ANN enabled smart antenna is used for monitoring, collecting data and analyzing. While the ANN enabled antenna offers some promising solutions to support the functions and operation of smart cities, challenges still exist.

In smart cities where everything is connected to something or everything, cyber security is a concern. The concern can lower the confidence and trust of the user in using the services offered by the smart city. Thus, the risk of doing too much for nothing will certainly hinder some progress in moving the development of smart cities. Another challenge dealing with intelligent communications system is the storing and handling of the massive data collected from all the sensors throughout the network. The location of the data can slow down system performance if the data is stored on servers too far from the user.

Addressing these challenges and others will enable reliable wireless communication in small cells for smart cities application using ANN enabled smart antennas.

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