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Revolutionizing Future Healthcare using Wireless on the Walls (WoW)

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Abstract— Following the standardization and deployment of fifth-generation (5G) network, researchers have shifted their focus to beyond 5G communication. Existing technologies have brought forth a plethora of applications that could not have been imagined in the past years. Beyond 5G will enable us to rethink the capability, it will offer in various sectors including agriculture, search and rescue and more specifically in the delivery of health care services. Unobtrusive and non-invasive measurements using radio frequency (RF) sensing, monitoring and control of wearable medical devices are the areas that would potentially benefit from beyond 5G. Applications such as RF sensing, device charging and remote patient monitoring will be a key challenge using millimetre (mmWave) communication. The mmWaves experience multi-path induced fading, where the rate of attenuation is larger as compared to the microwaves. Eventually, mmWave communication systems would require range extenders and guided surfaces. A proposed solution is the use of intelligent reflective surfaces, which will have the ability to manipulate electromagnetic (EM) signals. These intelligent surfaces mounted and/or coated on walls aka - ‘Intelligent Walls’ are planar and active surfaces, which will be a key element in beyond 5G and 6G communication. These intelligent walls equipped with machine learning algorithm and computation power would have the ability to manipulate EM waves and act as gateways in the heterogeneous network environment. The article presents the application and vision of intelligent walls for next-generation healthcare in the era of beyond 5G.

Index Terms—5G, B5G, Intelligent reflective surface, Millimetre-wave communication, RF sensing.

I. INTRODUCTION

THE emerging paradigm of programmable and software-defined metasurfaces will enable unprecedented technical solutions to drive unobtrusive and non-invasive sensing that could revolutionize the health-care sector. The healthcare industry is one of the biggest and fastest-growing industry in the world. A report published by the Allied Market Research

predicts that the healthcare market will reach \$136.8 billion worldwide by 2021 [1]. Remote patient monitoring is expected to maintain its lead position with \$72.7 billion until the same period. According to an estimate, there are 3.7 million medical devices in use that are connected to and/or monitor various parts of the human body to inform healthcare decisions. This has prompted researchers, academics and industry professionals to turn their attention to the introduction of the Internet of Medical things (IoMT). Over recent decades, there has been an enormous increase in the mobile and fixed wireless industry. In fact, mobiles have evolved from the analogue 1G voice system technology to the full-scale online and end-to-end digital 4G system (E2E). The beyond 5G (B5G) and future 6G wireless mobile communication systems will offer seamless access, enhanced Mobile Broadband (eMBB) with 1000x higher mobile data rates, Ultra-reliable and Low-Latency Communications (URLLC), i.e., 5x fewer delay optimised data [2-5]. B5G will serve as an innovation engine across multiple sectors including but not limited to smart agriculture, pharmaceutical industry, intelligent health care and many more. The existing networks do not have the potential and resources to offer these services. In a wireless communication system, important network parameters could be optimized to achieve higher data rates and low latency. The crucial parameters are: (1) enhancing spectral efficiency, (2) deploying more base station, i.e., increasing network density, and (3) shifting to high bandwidth signals. In this context, the B5G physical layer would be embedded with three important breakthrough technologies. This includes Massive MIMO (Multiple-Input-Multiple-Output) antennas for spectral efficiency [6], Ultra-Dense Networks (UDNs) [7] and utilizing the mmWave spectrum, i.e. 30-300 GHz for communication.

Recently, some network operators have already started field tests and trials of 5G networks with Massive MIMO technology operating in the sub-6 GHz spectrum. One of the fundamental challenge faced by network operators is the usage of ultra-high

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frequency-mmWave signals. The mmWave frequencies are prone to path loss, attenuation and atmospheric absorption [8]. The communication of mmWave networks is inherently limited to point-to-point operation only. In a wireless network, the conventional approach is to control and optimise transmitter and/or the receiver side only. The wireless propagation channel has been considered as a black box due to its random nature. With the desire to control the propagation environment, researchers have proposed new concepts such as field programmable metasurface [9] and intelligent reflective surface (IRS) [10-14]. With the ease of deployment and installation at both indoor and outdoor on any planar surface, they can be considered as ‘Intelligent Walls’ (IW). With the ability to manipulate the electromagnetic (EM) waves they would be assistive technology in B5G and provide a vision about the application of IW assisted health care in B5G and 6G communication. The paper is organized as follows: In section III, the working principle of IW is introduced and in section IV, a brief outline of the hardware architecture and mode of operation of IWs is discussed. Section V highlights the application and integration of machine learning (ML) with IW. In section VI, some important and potential use cases of IWs and their integration in various health care scenarios are briefly discussed. In the end, we provide potential future directions for IW in health care and future wireless communication.

II. CONFLUENCE OF B5G AND INTELLIGENT WALLS

This integration of IWs will have an important role in the B5G communication ecosystem. The ability of mmWaves to travel long distances is inherently hampered because it diffracts less than the microwave signals.

Consequently, it suffers from signal blockage, atmospheric absorption and attenuation to a greater extent. As electronically steering guided systems, IWs allow these high-frequency signals to be steered in the desired direction. In contrast to a parabolic antenna and phased array systems, these are planar, RF chain free systems with some memory and intelligence. Primarily, the IW will be seen as a dependent entity embodied in future wireless systems.

III. INTELLIGENT WALLS

In recent decades there has been enormous interest in textured metallic surfaces that attain properties not observed in nature. These surfaces are sometimes regarded as metasurfaces. A metasurface is an engineered surface that can be designed to perform or behave in a certain way. The elements on the metasurface with unique spatial arrangement have brought forth novel EM applications with unprecedented characteristics [15]. This has given rise to a novel paradigm in electromagnetics called ‘Surface Electromagnetics’ [16].

A metallic sheet is used as a reflector or a ground plane in many antenna designs. It has a constant impedance over the entire surface. On the contrary, a textured metallic surface with a subwavelength element size and interelement spacing can be designed to achieve desirable surface impedance [17]. The textured metallic surface element can act as an inductor or a

capacitor by keeping the dimension below the operating wavelength. Hence the reflection phase of the element can be tuned within the range of 360° .

Similar to a metallic sheet, the IW is a planar and textured metal surface supported by a metal-backed dielectric surface. The reflective property of each element can be controlled by tuning the surface impedance [18]. Each element on the IW acts as a scatterer which can provide phase lead or lag to the incoming wave. In a normal scenario, the surface of the IW is illuminated by an incoming plane wave or specifically by a horn antenna fixed in the near-field of the IW. The reflection phase of the individual scattering element can be combined in a manner such that it can produce the desired radiation pattern in the far-field. Based on the various phase profiles for multi-purpose applications, the IW can be programmed and controlled in real-time through the software platform [19]. The IW can simultaneously achieve the following operations in real-time.

Beamfocusing/Beamsteering/Multi-beam: An important property of the IW is to reflect the EM wave. Unlike parabolic surfaces, the planar metallic surface cannot focus the EM energy at a specific point. This is achieved by applying a concentric phase gradient over the entire IW surface [25]. Moreover, by merely adjusting the progressive phase shift among the elements would steer the focused beam to the desired direction for object tracking. Similarly, it is demonstrated in [20] that reflection phases of the individual field patterns; each with its desired reflected beam direction; when added together results in multiple beams generated by the IW. This is a useful feature for multiple object tracking and/or transmit energy in multiple beams.

Scattering Diffusion: Contrary to beam focusing, the IW can be configured to scatter the incoming EM signal in various directions [21, 22]. With a random phase distribution profile on the surface, the incoming wave is dispersed in various directions. This is an important characteristic which is used for imaging application. An IW for microwave imager employing EM wave scattering is demonstrated in [23].

Polarization control: Future communication systems intend to use multi-polarization schemes to exchange information over the channel. The IW can be configured to convert linear-to-linear and linear-to-circular polarization conversion [24, 25]. It is shown that by keeping a 180° phase difference between the elements in the x and y direction of the IW, the reflected wave will be transformed into a circularly polarized wave.

The list of functionalities attained by the IW is not limited to the aforementioned functions. A comprehensive article by the author [26] describes various high-level functions achieved by the IW. Moreover, it reviews the functionalities, architecture, advancements and challenges from the perspective of application-level down to the device level in the area of IWs. For the interest of the reader, a very simplistic architecture of the IW is briefly discussed in the next section.

IV. ARCHITECTURE OF INTELLIGENT WALLS

A simplistic architecture of the IW is illustrated in Fig. 1. Hence, the IW can be divided into three sub-parts.

EM layer: It consists of a top layer which comprises simple

metallic patches and active devices (e.g. PIN diodes) [9]. A conventional metal could be copper for mmWave signals or Gold/Graphene if Terahertz (THz) frequency is selected for operation [27]. The patches have sub-wavelength dimensions and inter-element spacing; giving them unique metasurface properties. The reflecting elements on the surface are usually placed in a periodic manner. By controlling specific properties of the active devices to further engineer the phase response of the metasurface, the incoming signal direction can be steered and/or if required can be diffused [19, 28].

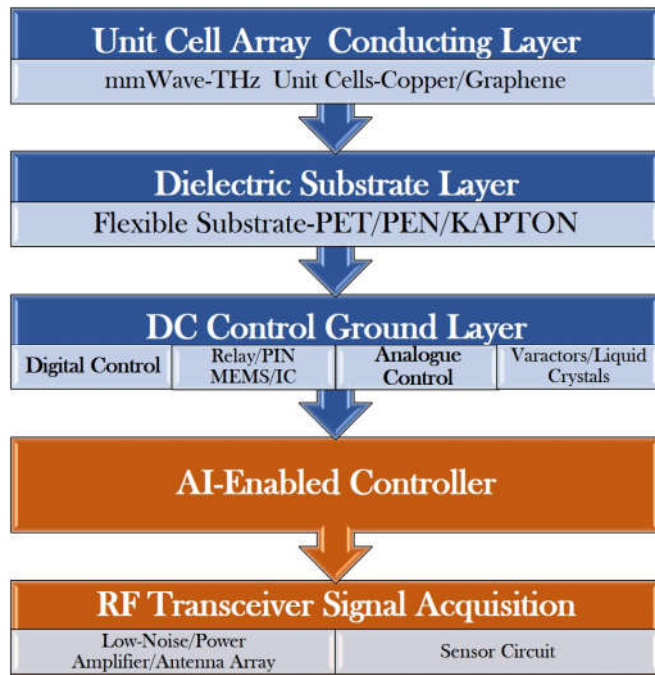


Fig. 1. A typical architecture of an intelligent reflective surface

Dielectric layer: Below the reflecting metal layer, this layer act as a dielectric spacer. The choice of the dielectric substrate is an important aspect of the IW design. An important design consideration is to have a thicker dielectric substrate with low dielectric constant. As a result, this would provide more element bandwidth [29]. The reflection efficiency may tend to decrease but can be improved by keeping the inter-element spacing below half-wavelength on the top metal layer [30]. Another obvious choice is to select flexible substrates with ease of deployment on any surface. The suitability of substrates is mainly dependent on the operating frequency. Each dielectric material provides a certain loss tangent at a particular frequency. Special attention is required if operating the IW at THz frequency. Conventional substrates at mmWave might not be a good choice in the ultra-high-frequency regime [31].

Ground layer: The third layer in the IW is the ground layer. The incident waves penetrating through the dielectric layer are reflected by the ground layer. At mmWave frequencies, this could be a simple copper metal.

RF signal sensing: A sub-component in the EM layer consists of a sensory circuit and an RF transceiver for RF signal acquisition and processing. Accordingly, the IW can be

operated in two basic modes - Active mode and Passive mode.

Passive mode: This is the conventional operation of the IW. The ambient signals can be collected from the wireless channel and electronically steered or focused to a certain point in space [23].

Active mode: In this mode, the IW would send beacon signals to the base station with the instructions from the controller embedded with IW. The IW will operate in passive mode, only to be active with a request from the controller. Hence, this should not be confused with the normal transceiver operation where a continuous stream of information is sent over the channel and transceiver is always in the ON state [23].

DC control layer: The second sub-part that is the non-RF circuit is primarily responsible to control the EM layer. Two methods of control can be employed on this layer. An analogue control which can normally consist of varactor diodes [32], BST capacitors [33] and/or liquid crystal technology [34] having high-resolution tuning ability to control the phase of the unit cell in the EM layer. As the realization of continuous tuning and control is cumbersome in real-time, digital control method using PIN diodes [9, 25], MEM switches [35], and/or relays [36] could be adapted for discrete control of the EM layer. The concept of digitally controlled metasurfaces [9, 37] has been lately proposed and gained significant attention from the research community. This emerging concept has eventually converged the information science domain with EM giving rise to programmable metasurfaces [9].

Controller Board: The control algorithm is normally applied through the controller which could normally be a microcontroller (MCU) unit or a Field Programmable Gate Array (FPGA) device. The higher clock speed of an FPGA makes it suitable for applications where a faster-switching operation is required.

V. INTELLIGENCE DRIVEN BY AI BRAIN

The functionality of reconfigurable metasurfaces, i.e., IWs, is mainly dependent on the sensing capability of the interface. Nonetheless, in typical practical scenarios, the optimization of many channel parameters based on sensed data, which is made available by sensors embedded into the IW, sets out requirements for large computing resource. To avoid continuous and iterative measurements and consume less power, Artificial Intelligence (AI) tools are envisioned to be embedded in the IWs to facilitate; by determining the best operation policy based on data-driven techniques [38]. The IW could be made adaptable, multi-functional and autonomous by incorporating AI into the system. Specifically, the incorporation of ML algorithms as a subfield of AI has revolutionized many realms of science and engineering and is foreseen to be enabled in IWs for a wide variety of applications. This stems from its capability to dynamically change the paradigm of data processing through the employment of algorithms that can learn from data and perform functionalities to complete complex tasks efficiently.

The concept has already been presented in some recent works [39-42]. A working prototype of a microwave reprogrammable digital metasurface [43] using ML algorithm is experimentally

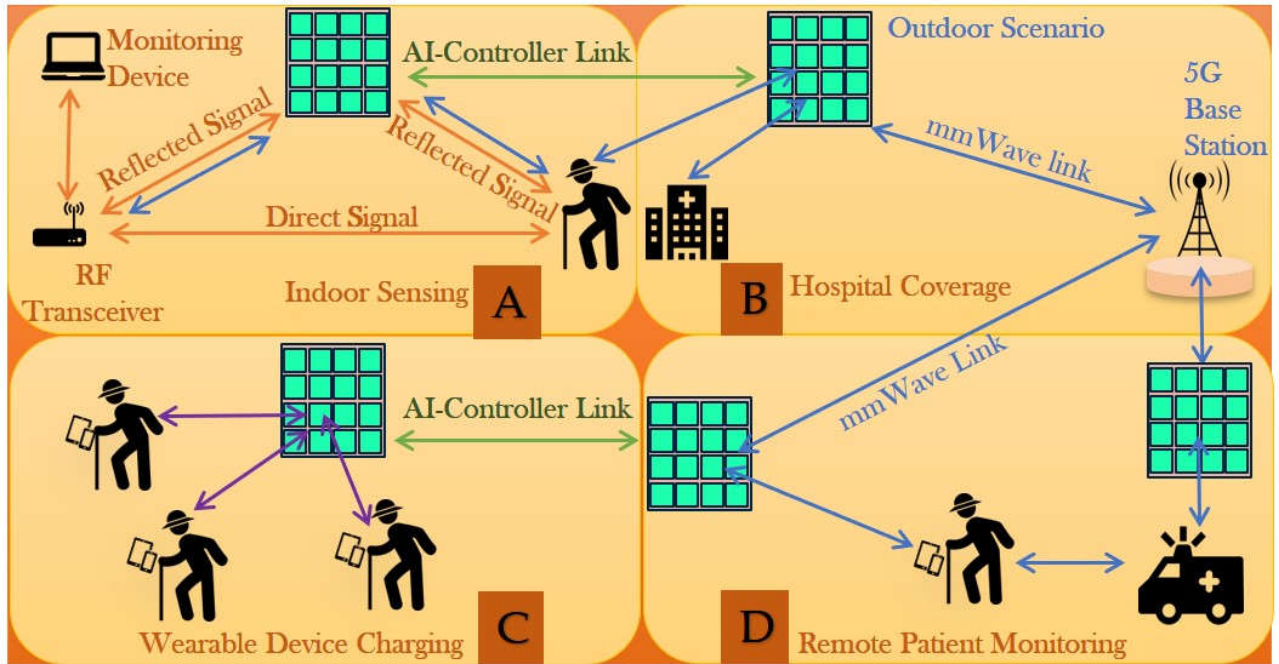


Fig. 2. Intelligent wall assisted different scenarios for health care use cases

demonstrated. It is shown that the data collected from the prototype is processed with the ML algorithm which can recognize various human gestures in real-time. The author(s) have also reported a first experimental IW prototype for EM sensing using ML algorithm for simultaneous data acquisition as well as data processing optimisation [44]. The proposed work significantly reduces the large number of measurements required for full scene-image and human body gesture recognition. Consequently, the results show the superior performance of the IW enabled EM sensing as compared to conventional sensing techniques. The proposed concepts have paved the way for future AI-enabled software-controlled reflective surfaces for different health care services.

VI. INTELLIGENT WALLS FOR ASSISTIVE HEALTH CARE

The introduction of B5G communication will contribute to the commercial deployment of many healthcare technologies, including tele-diagnostic testing, telemedicine, ECG (Electrocardiogram) telediagnosis, ultrasonic evaluation, and online training of doctors. With in-hospitals scenario, B5G will open a wide range of opportunities and applications that require ultra-reliable low-latency links such as robotic surgery performed remotely and augmented reality aided surgery. These state-of-the-art applications require low latency and transfer of high-quality videos and very large image data. With a plethora of health care applications, we identify some important use cases with the potential to use these intelligent surfaces to enable these applications with B5G.

A. Case I: Remote Monitoring/Telemedicine

The challenge of an ageing population is pushing toward novel healthcare provisions that evolves from the traditional hospital-based system, where patients are treated or monitored for severe health conditions in a controlled environment, to a

more person-centric approach. These patients can be observed in their homes remotely via 5G technology by identifying critical events such as freezing of gait and wandering behaviour. A home environment may typically block the incoming mmWave signals due to obstructions such as doors, windows and walls. For instance, the see-through the wall ability of the IW would make it possible to monitor patients behind thick objects [23]. Moreover, the placement of IW at designated places within the house would steer the beams to allow signals to reach the patient monitoring devices. As discussed earlier, the IW can generate multiple beams [20]; it will be useful for monitoring multiple patients within a nursing home. With assistance provided by the IW, the monitoring devices would typically relay back the patient data to a hospital network server. A typical scenario is depicted in Fig. 2, scenario A.

B. Case II: Indoor Coverage and Localisation In Hospitals

The B5G deployment may get complicated considering the resources and infrastructure requirements. Future wireless systems will use mmWaves which are located at the very high end of the spectrum, indoor communication and localisation will pose another challenge. Hospital buildings have metallic windows and metal frame-walls which will eventually block or either scatter the mmWave signals coming from 5G base stations. Due to planar nature and ease of deployment, these intelligent walls can be placed in corridors and around the corners within the hospital building for efficient indoor coverage. Localization involving mmWave frequencies will improve the accuracy from 10 m to below 1 m area [45], but the signals may not be able to propagate indoors efficiently. As IW can focus the beam towards any specific location and steer the beams for tracking, they will be able to assist in localization, mapping and tracking; by manipulating the signals to the desired locations [23, 46].

C. Case III: Charging Wearable Devices and Data Transfer

The IoMT can provide a better way to care for our patients and has a tremendous potential to help deal with the rising costs of care. The IoMT refers to a system of interconnected medical devices and applications that collect data and forward it to healthcare IT systems. These medical devices are typically referred to as wearable health care devices. One problem associated with these devices is that they need to be frequently charged; to keep them active and send patient data to the monitoring systems. An important application of the IW will be to provide a focused beam of energy to wirelessly charge wearable devices [23, 47]. The sensing circuit associated with the IW would listen to the beacon signal of the wearable device and focus the ambient RF energy towards the device when a specific battery threshold is reached.

At the same time, the majority of wearable devices employ backscatter communication and require dedicated transmitter in the vicinity to transfer information. Due to power constraints and inherent low-data-rate transmission of the wearable devices, they cannot transmit data over a longer distance and high data rate. IW assisted backscatter communication is recently demonstrated in [48]. By simply using the ambient signals from the propagation environment, the IW eliminates the need of a transmitter in the vicinity of a backscatter receiver. The IW thus can encode and modulate the ambient backscatter signal and can transfer data up to 500 Kbps to the receiver with a high Signal-to-Noise ratio [48]. Hence IW can simultaneously be used for charging and high data transfer in IoMT applications.

D. Case IV: Real-Time Feedback for Preventive Care Applications

A more specific scenario in assistive health care includes non-invasive sensing of patients [23, 49]. The mmWave signals could be used as an illuminator of opportunity where an ambient signal from 5G base station will be cross-correlated with echoes reflected from the subjects in the area under test, to extract information on their movements. With the help of ambient 5G signals, they can obtain full-scene images with high resolution and recognise human-body postures and vital signs with high accuracy in a smart, real-time and inexpensive way [23, 44]. The processing can be performed at the AI-enabled controller connected to the IW. The IW will act as a primary surface mounted indoors. In a situation where the patient has a symptom of a heart attack or an elderly patient falls over, the AI-enabled controller would instruct a secondary IW to redirect the ambient mmWave signal to the dedicated emergency response radio link. The IW could be mounted outdoor communicating with a 5G base station. It is important to mention that the AI controller could be connected to multiple IWs with different operational requirements. The application is demonstrated in Fig. 2, scenario A and D.

VII. FUTURE DIRECTION

The Internet of Humans (IoH) is a novel concept in health care, enabling elderly and patients to be connected, monitored and recorded via the internet. People can keep track of their health and fitness with wireless wearable technologies. It is therefore important to foresee how IWs could overcome new

technological barriers in the coming future.

mmWave-THz Imaging with IW: The ability of IW as an imaging system has already been demonstrated using WiFi signals[23]. This ability can be extended to operate in the mmWave and THz regimes as well. As the technology matures, we will expect to see miniaturized IW system used for diagnostics and imaging of patients.

Internet of Intelligent Walls (IoIW): The IW could be operated in a distributed network of IoIW. Analogous to a sensor network, the IW could be made to function as a plug and play device. A network of IWs connected with an MCU could be operated by AI-enabled controller link. The AI-enabled controller could be connected to several MCUs forming a cluster network of IWs. This could be interconnectivity of different hospitals and emergency services using IW.

Integration of IW in BAN: The IEEE 802.15.6–Body Area Networks (BAN) protocol is specifically designed for on-body communication. The wearable devices using this protocol operate in a strict battery saving mode and hence the signal connectivity in the practical scenario might be very low. The connectivity problem in low power mode could be solved with the integration of IW within BAN. The IW could collect weak signals from these devices and hence interlink with another wearable device in the vicinity.

Self-Adaptive IWs: Recently a self-adaptively smart metasurface has been proposed, in which a sensor or multiple sensors are integrated into the metasurface [50]. When the sensors detect different signals of the environment, the metasurface will automatically switch its functionalities without human operations. Based on this idea, a self-adaptive IW can be generated for smart home and health care, which could automatically operate in different modes under various environment conditions (e.g. daytime or night; temperature; humidity).

VIII. CONCLUSION

In this paper, we presented an overview of IWs and its potential to be integrated with future health care systems using B5G communication. The adaptation of mmWave spectrum for future wireless communication will provide users with enhanced data throughput, ultra-low latency and reliable communication. The requirement of broad coverage of mmWaves can be reached by integrating IWs in the wireless network. The IWs could smartly manipulate the signals and provide a full-duplex, interference-free communication link between the user and the base station. In the health care sector, the IWs can be seen charging a wearable device, monitoring patients in a non-invasive way and trigger to an emergency response unit by effective vital sign monitoring with AI-enabled technology. Through the presented discussion we can envision the integration and adaption of IW enabled communication with AI-enabled algorithms for future health care systems.

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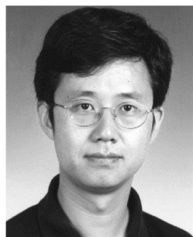
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