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An efficient WBAN aggregator switched-beam technique for isolated and quarantined patients

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Abstract

In this paper, an efficient beamforming technique at the aggregator node in the patient wireless body area network (WBAN) is proposed to improve the communication performance with the gateway node using C-shaped switched-beam antenna arrays. This proposed technique provides high gain beams towards the gateway node which may be located indoor or outdoor based on the medical quarantine or isolation topology and help medical staff monitor patients with less contact and infection probability. Also, a semi-blind switched-beam algorithm is developed to both reduce the processing time required for beam selection and reduce the power loss due to the off-mainlobe orientation of the selected beam with the signal direction. The proposed technique is analyzed at different wearing scenarios and simulation results show that the received power levels are improved with as less as 0.3 dBm standard deviation which helps in extending the communication range between the WBAN aggregator and gateway nodes in the health monitoring system and also extend the battery lifetime at the patient WBAN.

1. Introduction

1.1. Background

Our world faces pandemics due to the spread of severe and infectious viruses and the current outbreak is due to the new coronavirus disease 2019 (COVID-19) which spreads worldwide without exceptions, crossing all the boundaries with an exponential infection and death rates [1–3]. The main characteristic of COVID-19 is the fast infection between humans and results in severe health problems in human lungs and other body organs. Many studies show that the direct contact between COVID-19 patient or virus carrier causes the spread of infections and there should be restrictions on the human behavior especially the social distance which should be increased to prevent the virus high infection rate [3]. On the other hand, the frontline warriors dealing with COVID-19 patients are the health workers who face daily difficulties and suffer from the high possibility of infection and psychological problems. It has been reported that more than ninety thousands of health workers are infected worldwide with COVID-19 and many questionnaires have been conducted about the impact of this pandemic on the medical staff [4]; where they believed having social and professional problems regarding their safety and also their family’s safety. The medical staff also suffer from associated personal protective equipment headaches due to the continuous wearing of masks [5] where more than 80% of them have this diagnosis. The suffering increases with the increase of the health-care contact period of COVID-19 patients. A study in [6] has shown that the long period of being sleepless for medical staff leads to levels of stress and anxiety. Regarding patients, whether quarantined or isolated, suffer from limited and controlled movements especially who are in severe cases. The healthcare of these patients should be provided all the time they are quarantined or isolated with continuous monitoring from the medical staff which unfortunately increases the aforementioned problems. The very high infection rate of COVID-19 makes a huge burden on the health system of any country to deal with and to support every patient with the proper medical service. Home isolation or installing temporary field hospitals provides some of the solutions to accommodate every day infected people, however, there is a lack in the number of the medical staff. Therefore, and before the breakdown of the health system, technology should have the role to solve this problem where it should provide the continuous health monitoring to the huge number of patients by the limited number of the medical staff at a minimal stress and infection probability.
1.2. Related work

A patient can be remotely monitored through a wireless body area network (WBAN) where body sensors measure several health parameters such as EEG, ECG, EMG, Glucose level, and even audio or video data which are then packaged and transmitted through an aggregator node to a gateway station that is linked to the medical monitoring system [7–9]. The communication between body sensors and the aggregator is achieved locally on the patient body while the gateway node may be at a remote location depending on the transmitting power and antenna configuration of the aggregator node [8]. The transmitting aggregator power should be minimized to minimize the energy consumption at the patient WBAN which is mainly powered by a battery. Therefore, the antenna configuration at the aggregator should be selected carefully to achieve many objectives such as wearing flexibility, light weight, low profile, low complexity, and high gain. Many prototypes of the antenna structures of the WBAN have been proposed and the patch antenna array is the most tested one [10–16]. The flexibility of the wearable antenna array can be achieved by using flexible materials such as Polyethylene Terephthalate substrate [11], liquid crystal polymer substrate [16] and sometimes are embroidered on jeans wearable substrates [14]. The power pattern of the antenna array at the WBAN should be adapted to the communication conditions and environment in order to provide high gain and low specific absorption rate (SAR) toward the patient body. In [10], a one-turn circular antenna array has been proposed to improve the communication performance between the personal devices of the patient and its human body sensors. In [17], a beam-switching array for object detection purposes has been proposed where three independent beams can be generated from a flexible wearable antenna array. Other antenna structures have been proposed also such as the Yagi-Uda circular antenna array in [18] which has been designed at millimeter waves for WBAN applications. However, many of the recent WBAN antenna structures in literature do not provide any effective beamforming techniques from the aggregator node to provide efficient beams toward the gateway node to extend the battery lifetime and provide longer range of free movement for the patient without loss of connection with the medical monitoring system. Conventional WBAN is linked to the gateway node within a range of few meters and the higher power gain can be provided by generating narrow communication beams from the array to achieve maximum received/transmitted signal power.

1.3. Paper contribution

This paper proposes a switched beamforming technique to enable remote health monitoring and improve the communication performance between the medical system and isolated or quarantined patients to both provide patients (not suffering seriously from the disease) with freedom of motion and practice their life in the quarantine area and reduce the stress, fatigue, and possibility of getting infected for the medical supervising staff. The proposed system is composed of a patient WBAN with small sized switched-beam antenna array in the form of flexible and wearable coaxial C-shaped arrays at the aggregator node and a local gateway in the quarantine building. The WBAN antenna system at the aggregator forms directional beams that provides the highest signal for reception and transmission with the gateway node in the quarantine area. The increased signal power will help in reducing the energy consumption at the WBAN and hence a longer operational duration without the need for recharging the system batteries. The switched-beam technique is further improved by proposing a semi-blind algorithm that both reduces the processing time to select the most powerful beam and reducing also the power lost due to the off-pointing of the signal direction from the maximum gain of the selected beam. In addition, the proposed beamforming technique is examined for a number bending cases according to the wearing position of the array (around arm, abdomen side, and front abdomen).

1.4. Paper organization

The paper is organized as follows: Section 2 describes the health telemonitoring in temporary quarantine locations and hospitals. Section 3 demonstrates the proposed antenna array design and the corresponding parameters. Section 4 describes the proposed switched-beam techniques and their performances while Section 5 examines the array performance for different wearing positions and array openings. Finally, Section 6 concludes the paper.

2. Health telemonitoring system for field hospitals and quarantine locations

The medical monitoring system model during pandemics is shown in Fig. 1 where the patient body is telemonitored through a personal WBAN which is linked to the medical system via the aggregator sink node at which the proposed antenna system is existed. The main beamforming operation is done at the aggregator node to form directional beams toward the gateway node. The aggregator node can be fixed around arm, lower and upper parts of the leg, hamstring, waist or any other body part for the patient. The patient is assumed to be able to move freely in the quarantine region during the required period of time which is almost two or three weeks to stand on his infection and health status. Therefore, the WBAN and aggregator node should provide the system with the required data while supporting mobility in the quarantine or isolation place. If the infection occurred, then patients should stay isolated and monitored with much careful dealing and sometimes medical services should be provided remotely to reduce the infection probability. Medicines and food may be served by robots and the patient WBAN measurements should be also provided accurately with minimum energy consumption. This can be done by boasting the transmitted signal by using directional patterns which should be adapted with the patient movement and the gateway location. On the other hand, this portable patient network and the aggregator node should have less complexity and processing requirement. Therefore, the proposed system model is based on a switched-beamforming technique which selects a directional beam that provides the most powerful signal strength. Regarding the gateway, it may take several forms such as local fixed station or even a flying drone over the quarantine areas. The usage of drones as a gateway is very powerful in the case where the patients are quarantined in remote isolated buildings, so it can scan several quarantine areas to periodically collect patient data.

3. Conformal C-shaped antenna array design

In this section, the proposed conformal C-shaped antenna array is described and modeled. This array is formed by open-wall coaxial cylindrical array which can be flatted to almost planner array during the wearing of aggregator structure and is converted to the C-shaped coaxial arrays after fixing around any cylindrical body part such as the arm. The array elements are assumed to be uniformly inter-separated isotropic radiators to simplify the analysis. The power pattern generated is then multiplied with the real antenna element pattern to get the real array radiation pattern. The resulted array structure is shown in Fig. 2 where it is centered around the z-axis. The opening of the array will be aligned toward the body to reduce the body absorption and shadowing.
Fig. 1. Switched-beam communication network for health telemonitoring in isolation and quarantine locations.

Fig. 2. (a) Conformal C-shaped antenna array configuration, (b) body fixing methods.
The array response is therefore given by the following equation:

$$G_C(\theta, \phi) = \sum_{n=1}^{N} \sum_{m=1}^{M} w_m e^{j2\pi n m \cos(\phi_m) \sin(\phi)}$$  \hspace{1cm} (1)$$

where $N$ is the number of C-arrays, $M$ is the number of elements in each C-array, $r_n$ is given by:

$$r_n = \begin{cases} \frac{M}{2} \sin(\frac{\pi n \theta}{M}) \text{ for } n = 1, 2, \ldots, N \\ \frac{1}{2} \sqrt{\left(\frac{m}{2\pi} - \frac{\pi n}{M}\right)^2 + ((n-1)\theta)^2} \text{ for } n = 2, 3, \ldots, N \\ \end{cases}$$  \hspace{1cm} (2)$$

and $\phi_m$ is the azimuth angle of the $m^{th}$ antenna in any of the C-arrays which is determined by the following equation:

$$\phi_m = \frac{(m-1)}{(M-1)} (2\pi - \psi) + \phi_i, \text{ for } m = 1, 2, \ldots, M$$  \hspace{1cm} (3)$$

where $\psi$ is the opening angle of the C-shaped array and $\phi_i$ is the azimuth angle of the first element in the array which can be chosen according to the array orientation from 0 to $2\pi$ and measured from the x-axis.

The antenna elements are weighted by coefficients, $w_m$. These coefficients are responsible for the beam pattern formation and orientation. These weights should be chosen to boost the signal received in the tow-way communication link between the aggregator and the gateway station. On finding these weights, it should provide the following objectives:

1. Fast formation of directional beam pattern through a direct or simple signal processing technique.
2. Reconfigurable radiation pattern in case of changing the array geometrical shape during wearing the aggregator node structure.
3. Adaptation for changing conditions such as the presence of shadows around the patient or during movement.
4. Low sidelobe radiation pattern in order to save as much energy as possible.
5. Reduced backlobe radiation which will be towards the patient body.
6. Ability to provide powerful signal reception form the different body sensors.

The first objective listed above can be obtained by directly choosing the phase response of the weights as the complex conjugate of the exponential in Eq. (1) at the desired mainlobe direction ($\theta_o, \phi_o$) or:

$$w_{n,m}(\theta_o, \phi_o) = 2\mu_m \sin(\phi_m) \sin(\theta_m)$$  \hspace{1cm} (4)$$

The rest of the above objectives can be achieved to a high extent according to the adjustments of the amplitude coefficients $\alpha_{n,m}$ which may be chosen to smooth the radiation pattern and reduce the sidelobe levels where the following amplitude feeding profile is proposed:

$$\alpha_{n,m} = 0.5 + 0.6\cos(\mu_{n,m}) - 0.1\cos(3\mu_{n,m}) + 0.02\cos(5\mu_{n,m})$$  \hspace{1cm} (5)$$

where:

$$\mu_{n,m} = \frac{\pi \rho_{n,m}}{\sqrt{\left(\frac{n}{2}\right)^2 + \left(\frac{m}{2}\right)^2}}$$  \hspace{1cm} (6)$$

and

$$\rho_{n,m} = \sqrt{(n - \frac{N+1}{2})^2 + (m - \frac{M+1}{2})^2}$$  \hspace{1cm} (7)$$

The radiation pattern is examined for an array that is designed as shown in Fig. 3 where $N = 5, M = 8, \psi = 120^\circ$ and is fed with the proposed amplitude feeding profile as in Eq. (5). Fig. 4 displays the elements amplitude coefficients $\alpha_{n,m}$ where the innermost central elements have the maximum feeding amplitude. The 3D absolute power pattern is shown in Fig. 5 for a mainlobe that is directed toward $(90^\circ, 0^\circ)$ where the beam cross section is almost circular. The power pattern in dB is also displayed in the two planes corresponding to the mainlobe direction in Figs. 6 and 7 where the mainlobe direction gain is 25 dB while the highest backlobe level is about 17.5 dB that is 7.5 dB front-to-back level. The highest sidelobe level is 5.9 dB which is 19.1 dB below the mainlobe level. Not-
ing that, the weighting coefficients can be normalized by a certain value to obtain the desired mainlobe gain. The cross-sectional beamwidths (i.e. $BW_o$ and $BW_s$) are approximately 32° in the two directions which is the narrowest possible beamwidth obtained from the array as array projection area is maximum at this mainlobe direction.

4. The proposed switched-beam technique

There are many beamforming techniques that can optimize the array radiation pattern [19–21], however, in the current application, the major objective is to simplify the aggregator system while providing most of the mentioned objectives. So, we may apply the switched-beam technique [22–23] which provides high gain beams toward the desired signal directions. The switched-beam antenna systems test the signal received power in fixed mainlobe directions and selects the one which provides the maximum value among the beams. The selection has no priori information about signal direction-of-arrival of the signals or the gateway node and therefore can be called 'Blind switched-beam technique' and will be demonstrated for the current application. A modification on this technique is proposed in this paper to improve the communication performance and speed of beam switching at low processing cost which is named as 'Semi-blind switched-beam technique'. First, the array data model is deduced for the purpose of signal power calculation at the aggregator node which is necessary in choosing the proper mainlobe direction for data sending from the aggregator node. Then, the blind and semi-blind switched-beam techniques are demonstrated with performance comparisons.

4.1. Array data model

In this section, we assume a beacon signal from the gateway node is used to define the most powerful beam generated at the aggregator node of a mainlobe direction $\theta_n$ which will be used for transmission of sensed data. Assuming that a signal $s(k)$ is impinging on the array from a direction $(\theta_s, \phi_s)$, so, the $k^{th}$ sample of the received signal at the $nm^{th}$ antenna element from the gateway node, $X_{n,m}^{(k)}(\theta_s, \phi_s)$, with a Gaussian noise, $\eta_{n,m}$, can be modelled as follows:

$$X_{n,m}^{(k)}(\theta_s, \phi_s) = s(k)e^{2\pi j X_{n,m}(\cos(\theta_s)\cos(\phi_s)\sin(\phi_s) + \sin(\theta_s)\sin(\phi_s))} + \eta_{n,m} \quad (8)$$

Then, the $k^{th}$ output sample at this element can be written as:

$$y_{n,m}^{(k)}(\theta_s, \phi_s) = W_{n,m}(\theta_s, \phi_s)(X_{n,m}^{(k)}(\theta_s, \phi_s) + \eta_{n,m}) \quad (9)$$

and the total output from the array is given by:

$$y^{(k)}(\theta_s, \phi_s) = \sum_{n=1}^{N} \sum_{m=1}^{M} W_{n,m}(\theta_s, \phi_s)(X_{n,m}^{(k)}(\theta_s, \phi_s) + \eta_{n,m}) \quad (10)$$

So, the average output power can be calculated as follows:

$$P_y(\theta_s, \phi_s) = \frac{1}{K} \sum_{k=1}^{K} y^{(k)}(\theta_s, \phi_s)(y^{(k)}(\theta_s, \phi_s))^H + \sigma_n^2 \quad (11)$$

where $(y^{(k)}(\theta_s, \phi_s))^H$ is the complex conjugate of $y^{(k)}(\theta_s, \phi_s)$, $H$ is the Hermitian operator and $\sigma_n^2$ is the noise variance at the output of the beamformer.

4.2. Conventional blind switched-beam technique

The spatial channel response depends on the spatial beamwidth generated by the C-shaped array which forms a beam solid angle to
scan the whole $4\pi$ steradian solid angle. Therefore, the switched beam spatial resolution determines the number of elements in the channel spatial power vector which can be written as follows:

$$P_s = \begin{bmatrix} p_{v_0}(0) \\ p_{v_0}(B_0) \\ p_{v_0}(2B_0) \\ \vdots \\ p_{v_0}(uB_0) \\ \vdots \\ p_{v_0}(UB_0) \end{bmatrix}$$

(12)

where $p_{v_0}(uB_0)$ is a power sub-vector calculated at the direction $\theta = uB_0$ with $u = 0, 1, 2, \ldots, U$. $B_0$ is the beam scanning resolution in the $\theta$-direction and $U = 180/B_0$ rounded to the nearest higher integer. $v = 0, 1, 2, \ldots, V_u$ where $V_u = 360\sin(uB_0)/B_0$ rounded to the nearest higher integer where $B_0$ is the beam scanning resolution in the $\phi$-direction. The elements of $p_{v_0}(uB_0)$ is calculated for $u = 1, 2, \ldots, U - 1$ as follows:

$$p_{v_0}(uB_0) = \begin{bmatrix} p_0(uB_0, 0) \\ p_0(uB_0, \frac{B_0}{2\sin(uB_0)}) \\ \vdots \\ p_0(uB_0, \frac{uB_0}{\sin(uB_0)}) \\ \vdots \\ p_0(uB_0, \frac{UB_0}{\sin(uB_0)}) \end{bmatrix}$$

(13)

with the following initial single element vectors: $p_{v_0}(0) = [p_0(0, 0)]$ and $p_{v_0}(UB_0) = [p_0(UB_0, 0)]$.

The number of operational beams is the same as the length of the spatial power vector or:

$$N_b = \text{Length}(P_s)$$

(14)

Noting that the operating mainlobe direction ($\theta_0, \phi_0$) may not be the same as the signal direction ($\theta_s, \phi_s$) which results in some loss in the signal power. Assume that the off-pointing in beam orientation which is the absolute difference between the mainlobe and signal directions can be expressed using the following equations:

$$\delta_\theta = |\theta_0 - \theta_s|$$

(15)

and

$$\delta_\phi = |\phi_0 - \phi_s|$$

(16)

And the loss in the received signal power is given by:

$$\delta_P = P_s(\theta, \phi) - P_s(\theta_0, \phi_0)$$

(17)

In the blind switched-beam technique, the whole beam directions are tested in $P_s$ and the optimum operating beam, $(\theta_0, \phi_0)_{\text{opt}}$, is determined the minimum value of $\delta_P$:

$$(\theta_0, \phi_0)_{\text{opt}} = (\theta_0, \phi_0)_{\text{min}}$$

(18)

Figs. 8–13 display the performance of a typical blind switched-beam system for an array designed as in Fig. 3 with a spatial pointing resolution of $16^\circ$ that uses about 162 beams for selection as shown in Fig. 8. Assuming a signal power of $-70$ dBm coming forming $(75^\circ, 60^\circ)$, the spatial normalized power response of the array calculated from Eq. (12) is shown in Fig. 9 neglecting shadowing effects and considering only line-of-sight component. The optimum selected beam for this signal direction is $(80^\circ, 68^\circ)$ resulting in $\delta_\theta$ and $\delta_\phi$ to be $5^\circ, 8^\circ$ respectively. The process is tested for 1000 switching operation for a randomly impinging signal on the array and the off-pointing $\delta_\theta$ and $\delta_\phi$ are shown in Figs. 10 and 11.
As the values of \( \delta_\theta \) and \( \delta_\varnothing \) increases, the loss of power due to off-pointing increases as shown in Fig. 12. As it is recommended to reduce the spatial pointing resolution to minimize the loss of power, this results in larger spatial pointing matrix and hence more processing time and slower beam switching.

Fig. 13 concludes the beam selection process for 1000 randomly changing beam direction where average off-pointing in both directions is zero and the average received power is approximately –45 dBm indicating an array power gain of 25 dB.

The effect of spatial switching resolution on system performance is very important. As a case study, we use the same array design as in Fig. 3. The switching angular resolution is set at several values as shown in Table 1 as a function of the average beamwidth of the array which is 32° for this design. The array is assumed to be fixed around the arm with an opening angle \( \psi = 120° \). Assuming that an average received signal power at the antenna element is –70 dBm with white Gaussian noise and SNR of 20 dB. This received signal is used as a beacon for selecting the most powerful beam according to Eq. (14). Several performance indicators are measured in this table such as the mean and standard deviation of the received power, the number of processed beams, the variation between the selected mainlobe direction and the actual direction of arrival of the signal, the processing time relative to that for the largest beam switching angles. It is clear from Table 1 that using condensed beams (i.e. at smaller values of \( B_\theta \) and \( B_\varnothing \)) results in less loss of the transmitted or received power (or less values of the standard deviation \( \delta_\theta \)) due to beam switching as \( \delta_\theta \) and \( \delta_\varnothing \) become smaller while the processing time increases exponentially. The large relative processing time in the blind switched-beam technique is not an issue for slowly changing communication environment with almost stable or slowly moving patient, however it will not be suitable for fast changing environment and signals may be lost due to the lag in tracking. Therefore, in the next section, this algorithm will be modified to provide less loss of power and reduced processing time.

4.3. The Semi-Blind Switched-Beam Technique:

The main problem in conventional blind switched-beam technique is the size of the spatial power vector where there should be a compromise between beam pointing accuracy of and speed of calculations for beam selection. The length of the spatial power vector, \( N_s \), increases significantly by decreasing the beam scanning resolution \( (B_\theta, B_\varnothing) \) as shown in Fig. 14. High resolution beam scanning results in more power calculations and slower beam switching operation. In fast changing environments where the patient may move frequently or there are surrounding moving objects, the received signals change rapidly which results in frequent beam switching. Therefore, in this section, the benefits of both high and low resolution techniques are combined to obtain semi-blind beam scanning. The technique is performed in two steps where a low resolution fast beam scanning is performed in the first step to determine the spatial range of a limited window of high resolution scanning in the second step.

According to the array configuration and beamwidth, the high-resolution scanning window can be chosen as twice the beamwidths:

\[
\theta_{\text{ref, opt}} - BW_\theta \leq \theta_{\text{ref}} \leq \theta_{\text{ref, opt}} + BW_\theta
\]

(19)

\[
\varnothing_{\text{ref, opt}} - BW_\varnothing \leq \varnothing_{\text{ref}} \leq \varnothing_{\text{ref, opt}} + BW_\varnothing
\]

(20)

where \( BW_\theta \) and \( BW_\varnothing \) are the beamwidths in the \( \theta \) and \( \varnothing \) directions respectively, \( \theta_{\text{ref}} \) and \( \varnothing_{\text{ref}} \) are the high-resolution beam pointing angles while \( \theta_{\text{ref, opt}} \) and \( \varnothing_{\text{ref, opt}} \) are the optimum low-resolution selected beam pointing angles.

Fig. 15 displays the grid of beam searching where the low-resolution case uses 32° angular beam spacing and this grid is used to detect the optimum beam pointing \( (128°, 315°) \) for a signal coming from \( (130°, 308°) \). Fig. 16 displays a window of high-resolution stage formed at 8° angular resolution that refine the optimum beam direction to \( (130°, 307°) \) which is more accurate. For 1000 beam switching operations, Figs. 17 and 18 display the off-pointing in the two directions where they are reduced in range as compared with those in Figs. 10 and 11. On the other hand, the average received power is shown in Fig. 19 where the variation around the mean value is reduced and Fig. 20 concludes the performance of the semi-blind switched beam technique.

4.4. Performance comparison between conventional blind and semi-blind switched-beam techniques

In this section, a performance comparison between the conventional blind and semi-blind switched-beam techniques is held. The first important comparison item is the required beam selection processing time which is directly related to the number of processed beams and is shown in Fig. 21 assuming all array
parameters are kept constant. The values are normalized to the processing time required in the case of blind switched-beam technique at resolution of 32°. The processing time is reduced greatly by using the semi-blind technique especially at small resolution searching angles compared with the conventional blind switched-beam technique. Changing the window size of the semi-blind technique has minimal effect on the processing time. In general, the processing time remains almost constant even we reduce the angular search resolution.

A detailed performance comparison is displayed in Tables 2 and 3 where the received power performance is described in terms of minimum, average, maximum, and standard deviation values regarding the impact of beam switching only of the blind and semi-blind techniques. The low resolution grid uses the beamwidth \( BW \) as the angular search resolution while the high resolution grid uses smaller values such as \( BW/2 \), \( BW/3 \), and \( BW/4 \). The effect of reducing the angular spacing between search beams in the semi-blind technique is very important as it reduces...
Fig. 14. Variation of the number of processed beams with the beam scanning resolution.

Fig. 15. Low resolution switched-beam space pointing matrix.

Fig. 16. High resolution limited switched-beam space pointing matrix.

Fig. 17. Off-pointing of the selected beam with the signal for $\theta$ direction for the semi-blind switched-beam technique.

Fig. 18. Off-pointing of the selected beam with the signal for $\phi$ direction for the semi-blind switched-beam technique.

Fig. 19. Received signal power variation due to beam switching for the semi-blind switched-beam technique.
the standard variation and range between minimum and maximum values of the received power while the processing time is kept very low.

5. Effects of array surface bending for different wearing positions

In this section, the proposed array is examined in case of being flattened or more bent. Assuming that the bending is done only in the $xy$-plane where the array opening angle $\psi$ is either increased or decreased at constant number of elements. Recalling Eq. (2), the array radius $r_1$ according to this assumption will be:

$$r_1 = M \left( \frac{\psi}{2(2\pi - \psi)} \right)$$

(21)

where $\psi$ is the opening angle of the array. Fig. 22 displays the variation of array radius with the array opening angle at variable number of elements in the base C-shaped array $(M)$.

The array radius increases by increasing the array opening angle with almost linear profile especially for opening angles less than $180^\circ$ while at large opening angles greater than $300^\circ$, the array radius increases very rapidly and at $\psi = 360^\circ$, the array radius tends to infinity which corresponds to the planer array structure. The radiation pattern of the changing radius array is therefore lying between two limiting cases which are the cylindrical array ($\psi = 0^\circ$) and the planar array ($\psi = 360^\circ$) configurations as shown in Fig. 23.

Table 4 displays the array radiation characteristics of a conformal C-shaped array of $N = 5$ and $M = 8$ with inter-element spacing of $0.35\lambda$ that generates a beam toward $(90^\circ, 0^\circ)$ and with $\psi = 0^\circ, 120^\circ, 180^\circ, 240^\circ, 270^\circ$ and $300^\circ$ and feeding profile as proposed in Eq. (5). The impact of opening the array is clear on reducing the beamwidth in the $\phi$-direction due to the increased projection area, the sidelobe level decreases to 20 dB below the mainlobe level while there is an increase in the backlobe level which is common in planar arrays, and the array absolute gain is constant at 25 dB. The increased backlobe level can be reduced in the real antenna design such as the patch antenna structures.
The different array bending is due to different array fixing positions. As shown in Table 5, the performance of the proposed array and switched-beam technique is almost constant and independent on the array curvature. The standard deviation of the power due to switching is constant, therefore, the proposed array can be used at different wearing positions without affecting the communication performance which presents a great flexibility for the patient. For example, if the patient temporarily wears off this conformal array and keep it nearby him, the system performance does not deteriorate and still work.

Fig. 22. Variation of the array radius with the array opening angle at different C-array size.

Fig. 23. C-shaped array base configuration at different array opening angles.

| Performance parameters (\(\phi \text{ BW} = 32^\circ\)) | Beam switching technique |
|-------------------------------------------------------|--------------------------|
| Window = 2BW \times 2BW                                |                          |
| Normalized beam switching time                        |                          |
| Blind (BW)                                             | 1                        | 3.96 | 1.45 | 8.39 | 1.72 | 14.64 | 1.85 |
| Blind BW/2                                             | -49.2                    | -46.1 | -47.5 | -45.8 | -46 | -45.5 | -45.2 |
| Semi-Blind BW + BW/2                                   | -44.5                    | -44.4 | -44.3 | -44.2 | -44.5 | -44.2 | -44.2 |
| Semi-Blind BW + BW/3                                   | -46                       | -45.2 | -45.3 | -45 | -45.1 | -44.86 | -45 |
| Standard deviation of the variation in received power (dBm) | 0.8                      | 0.28 | 0.48 | 0.22 | 0.27 | 0.2 | 0.33 |

Table 3
Performance comparison between blind and semi-blind switched-beam techniques at high-resolution window of BW \times BW.

| Performance Parameters (\(\phi \text{ BW} = 32^\circ\)) | Beam Switching Technique |
|-------------------------------------------------------|--------------------------|
| Window = BW \times BW                                  |                          |
| Normalized beam switching time                        |                          |
| Blind (BW)                                             | 1                        | 3.96 | 1.187 | 8.39 | 1.2 | 14.64 | 1.5 |
| Blind BW/2                                             | -49.2                    | -46.1 | -47.7 | -45.8 | -47.3 | -45.5 | -47.8 |
| Semi-Blind BW + BW/2                                   | -44.5                    | -44.4 | -44.3 | -44.2 | -44.3 | -44.2 | -44.2 |
| Semi-Blind BW + BW/3                                   | -46                       | -45.2 | -45.3 | -45 | -45.1 | -44.84 | -44.9 |
| Standard deviation of the variation in received power (dBm) | 0.8                      | 0.28 | 0.39 | 0.22 | 0.37 | 0.2 | 0.32 |

Table 4
Performance of C-shaped array at different opening angles or curvature.

| Performance parameters | Array opening angle (\(\phi\)) |
|------------------------|-------------------------------|
| Beamwidth              | 0°   | 120° | 180° | 240° | 270° | 300° |
| Beamwidth (\(\phi\)-direction) | 32°   | 32° | 32° | 32° | 32° | 32° |
| Mainlobe power gain (dB) | 25 dB | 25 dB | 25 dB | 25 dB | 25 dB | 25 dB |
| Highest sidelobe level (dB) | 18.5 dB | 17.5 dB | 17.5 dB | 9 dB | 6.7 dB | 5 dB |
| Backlobe level (dB)     | 10 dB | 14.8 dB | 18.8 dB | 19.7 dB | 21 dB | 22.8 dB |
Table 5
Performance of C-shaped array at different fixing positions.

| Performance parameters | Array flange angle (α) in degrees and array fixing position | Arm fixing (ψ = 120°) | Abdomen side fixing (ψ = 240°) | Abdomen front fixing (ψ = 270°) |
|------------------------|----------------------------------------------------------|-----------------------|-------------------------------|-------------------------------|
| (δ)max (in degrees)    | 0°                                                       | 0°                    | 0°                            |
| (δ)3max (in degrees)   | 15°                                                      | 15.7°                 | 15.55°                        |
| Average δ0 (in degrees)| 0.3°                                                     | 0.14°                 | 0.13°                         |
| Δθ Standard deviation  | 5.3°                                                     | 5.7°                  | 5.75°                         |
| Δθymin (in degrees)    | 0°                                                       | 0°                    | 0°                            |
| Δθy = 16°              | 16°                                                      | 16°                   | 16°                           |
| Average Δθx (in dBm)   | 0°                                                       | 0.13°                 | 0°                            |
| ΔΦ Standard deviation  | 6.17°                                                    | 5.8°                  | 5.7°                          |
| Pmax in dBm            | -46.10                                                   | -46.1                 | -46                           |
| Pmin in dBm            | -44.40                                                   | -44.2                 | -44.1                         |
| Average P in dBm       | -45.20                                                   | -45.13                | -45.11                        |
| ΔP Standard deviation of the power | 0.28                                                    | 0.3                   | 0.3                            |

6. Conclusions

The virus pandemics such as the new 2019 coronavirus (COVID-19) has affected the whole human activities especially the medical utilities and health workers. This paper has proposed an efficient communication system for remote health monitoring of isolated and quarantined patients that safely help them cure without increasing the infection rate and encouraging the medical staff to continue work efficiently. A flexible and wearable open wall cylindrical array (C-shaped array) has been designed with efficient semi-blind switched-beam technique to provide high gain beams originating from the patient WBAN which allows him/her to move freely in the quarantine area, provide longer communication range, and effective energy consumption. The proposed technique is described and the system performance is demonstrated where analysis and simulation results show that the array achieved power and the processing time have been improved. The array is also analyzed for different wearing positions where it maintains its rigid performance. In the future work, patients in several quarantine locations will be monitored by flying gateway drones to collect the patient medical information in rural areas, which allows remote health monitoring for multiple locations in an efficient periodical scheduled manner.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aeue.2020.153322.

References

[1] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen.
[2] https://www.cdc.gov/coronavirus/2019-ncov/index.html.
[3] https://www.worldometers.info/coronavirus/.
[4] Cai H, Tu B, Ma J, et al. Psychological Impact and Coping Strategies of Frontline Medical Staff in Hunan Between January and March 2020 During the Outbreak of Coronavirus Disease 2019 (COVID19) in Hubei, China. Med Sci Monit. 2020;26:e924171. Published 2020 Apr 15, doi:10.12659/MSM.924171.
[5] Ong JY, Bharatendu C, Goh Y, et al. Headaches associated with personal protective equipment – a cross-sectional study among frontline healthcare workers during COVID-19. Headache 2020;60(5):864–77. https://doi.org/10.1111/head.13814.
[6] Xiao H, Zhang Y, Kong D, Li S, Yang N. The Effects of Social Support on Sleep Quality of Medical Staff Treating Patients with Coronavirus Disease 2019 (COVID-19) in January and February 2020 in China. Med Sci Monit 2020;26:e923549. Published 2020 Mar 5. doi:10.12659/MSM.923549.
[7] Bayrakdar ME. Priority based health data monitoring with IEEE 802.11af technology in wireless medical sensor networks. Med Biol Eng Comput 2019;57(12):2757–69. https://doi.org/10.1007/s11517-019-02060-4.
[8] Calhan A, Gündoğdu Kıslar, Cicekçi Muratza, Enes Bayrakdar Muhammed. Energy harvesting unit design for body area networks. Sakarya University J Comput Inform Sci 2019;2(1):41–52.
[9] Bayrakdar ME. Fuzzy logic based coordinator node selection approach in wireless medical sensor networks. In: 2019 4th International Conference on Computer Science and Engineering (UBMK); Samsun, Turkey; 2019. pp. 340–343. doi:10.1109/UBMK.2019.8907097.
[10] Li Yang, Yang Licheng, Gao Meng, Xiao Zhaoan, Zhang Xin. A study of a one-turn circular patch antenna array and the influence of the human body on the characteristics of the antenna. Ad Hoc Networks, Volume 99, 2020, 102059, ISSN 1570-8705, https://doi.org/10.1016/j.adhoc.2019.102059.
[11] Farooq U et al. Design of a 1×4 CPW Microstrip Antenna Array on PET substrate for Biomedical Applications. 2019 IEEE International Symposium on Antennas and Propagation, and USNC-URSI Radio Science Meeting, Atlanta, GA, USA; 2019. p. 1345–1346, doi:10.1109/APUSCIRSN.2019.8889355.
[12] Hong Y, Choi J. 60-GHz Array Antenna for mm-Wave 5G Wearable Applications. In: 2018 IEEE International Symposium on Antennas and Propagation & USNC-URSI National Radio Science Meeting, Boston, MA, USA; 2018. p. 1207–1208, doi:10.1109/APUSCIRSN.2018.8608603.
[13] Mao C, Werner PL, Werner DH, Vital D, Bhardwaj S. Dual-polarized armband embroidered textile antenna for on-off-body wearable applications. In: 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Atlanta, GA, USA; 2019. p. 1555–1556, doi:10.1109/APUSCIRSN.2019.8889041.
[14] Sanjeeva Reddy BK, Vakula D, Raula Kumar A. Performance analysis of Wearable Antenna Array for WLAN applications. In: 2018 IEEE Indian Conference on Antennas and Propagation (InCAP); Hyderabad, India; 2018. p 1–4, doi:10.1109/INCAP.2018.8770832.
[15] Zhang K, Jiang ZH, Hong W, Werner DH. A low-profile and wideband triple-node antenna for wireless body area network concurrent on-off-body communications. IEEE Trans Antennas Propag 2020;68(3):1982–94. https://doi.org/10.1109/TAP.2019.2948700.
[16] Saeed MA, Ur-Rehman M. Design of an LCP-based Antenna Array for 5G/B5G Wearable Applications. In: 2019 UK/ China Emerging Technologies (UCET), Glasgow, United Kingdom; 2019. p. 1–5, doi:10.1109/UCET.2019.8881850.
[17] Mereved A, Klinovskii K, Shamin A. Screen-printed, flexible, parasitic beam-switching millimeter-wave antenna array for wearable applications. IEEE Open J Antennas Propagat 2020;1:1–10. https://doi.org/10.1109/OJAP.2019.2955507.
[18] Kumar DA, Khan MZA. A millimetre wave embroidery beam forming antenna array for UWB applications. In: 2018 Progress in Electromagnetics Research Symposium (PIERS-Toyama), Toyama, 2018. pp. 935–939, doi:10.23919/PIERS.2018.8598016.
[19] Kaboutari K, Zbib H, Virdée B, Pilevir Salimani Mostaﬁ. Microstrip patch antenna array with constant-squared radiation pattern profile. AEU – Int J Electron Commun 2019;106:82–88, ISSN 1434-8411, https://doi.org/10.1016/j.aeue.2019.05.003.
[20] Noﬁ Mostafa, Aljahdali Sultan, Albayrak Yasser. Tapered beamforming for concentric ring arrays. AEU-Int J Electron Commun 2013;67(1):58–63.
[21] Ismaiel Ayman, Elsaidy Elsayed, Albayrak Yasser, Atallah Hany, Abdel-Rahman Adel, Sallam Tarek. Performance improvement of high altitude platform using concentric circular antenna array based on particle swarm optimization. AEU – Int J Electron Commun. 2018;91:85–90. https://doi.org/10.1016/j.aeue.2018.05.002.
[22] Nishesh Tiwari, Thipparaju Rama Rao. A switched beam antenna array with butter matrix network using substrate integrated waveguide technology for 60GHz wireless communications. AEU - International Journal of Electronics and Communications 2016;70(6):850–856, ISSN 1434-8411.
[23] Ibrahim SZ, Rahim MK. Switched beam antenna using omnidirectional antenna array. 2007 Asia-Pacific Conference on Applied Electromagnetics, Melaka; 2007. p. 1–4, doi:10.1109/ACE.2007.4603921.