ENHANCEMENT OF COMMUNICATION QUALITY IN MULTIPLE USERS SCENARIO IN ON-BODY CHANNELS THROUGH THE USING OF INTERFERENCE CANCELLATION TECHNIQUES

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ABSTRACT
As the body-are networks will probably operate in a multiuser context in the near future, interference cancellation techniques will be an important part of the communication system. To address this, a multi-user environment is emulated by using real time measurements of one interferer walking around the desired user in an indoor environment. For the interference mitigation part, two modified versions of the Wiener-Hopf and optimum combining approaches are adopted for weight calculation in two on-body wireless communication channels. The two channels are generated by placing the transmit antenna at the belt position and the receive antenna at the head and chest positions thus forming the belt-head and the belt-chest links. The interference rejection capability of these two algorithms is evaluated through the output signal-to-interference-plus-noise (SINR) ratio enhancement. It is shown that in this particular indoor environment, and due to the channel correlation, the achieved interference rejection capacity of the Wiener-Hopf solution is limited particularly in the belt-chest channel unlike the optimum combining which exhibits a high robustness to multiple access interference.

Keywords: *body-area-networks, interference cancellation, Wiener-Hopf, Optimum combining*

1. INTRODUCTION

Body-area- networks (BANs) are gaining more research interest because the design technology is there to back up the concept [1-3]. They are expected to bring radical changes in the services offered in patient monitoring in the hospitals, residential and work environments as well as in multimedia entertainment and military applications. For instance, a permanent diagnostic of the patient located at home may be achieved by allowing distant and secured access to his critical and non-critical data from the hospital upon which an emergency procedure is launched whenever the vital signs look critical. This will result in the enhancement of the medical quality of service at the hospitals, the solving of the emergency service queue problem and the reduction of the work load on the medical staff. As they are using low cost low power wireless sensor body-worn devices, the hardware design should not involve any high level complexity.

The body centric communications (BSC) may involve on-body links, in-body links or off-body links. On-body systems refer to the particular case where both the transmitter and the receiver are placed on a single human body. In hospital scenarios, on-body channels are susceptible to interference from neighboring BANs because of the likely presence of a certain number of patients equipped with body worn devices. In such scenarios, implementing efficient techniques for the cancellation of interference and the improvement of desired user signal quality becomes an imperative. Spatial processing using smart antennas has been envisaged in conventional wireless systems, but becomes challenging in BANs. Moreover, the techniques based on eigen decompositon (ED) show high efficiency for improving communications system performance but when strong interfering signals come from directions close to desired-user-signal direction, these methods are also limited. For the case of BANs, the main hindrance of these techniques is that they necessitate the prior knowlege of the desired signal direction which may render the antenna system quite complex [7]. Indeed, owing to the proximity of the transmit and receive antennas on the body, the plane wave assumption as stated for conventional wireless systems assessing their operation in the far field propagation is no more valid. Instead, a 3D angle of arrival estimation and spatial filtering methods should be used. In the best case where accurate angle estimates can be obtained with high-precision equipment, the subsequent computation load might become prohibitive for BANs. Furthermore, one shortcoming with spatial processing arises when the desired user and the interferers are correlated, which may happen in the presence of a high number of users and accordingly desired signal cancellations occurs. To prevent this, previous approaches have used averaging over either space or frequency to break the coherence prior to beamforming but this will burden the BAN and still implies the estimation of signal and interferences directions which is hardly feasible.

Most of the work on using multiple receive antennas emphasize on the improvement in the desired signal strength and the increase of the diversity gain [4]. Only few research efforts have been deployed for BAN-BAN interference rejection for the on-body channels [3].

Spatial combining technique may be used at the receiver side equipped with multiple antennas, and a sufficient level of interference rejection can be achieved provided that the desired signal and the interference are uncorrelated. This is the case for the interference rejection combining (IRC) techniques which achieve their interference cancellation target by increasing the output signal to interference plus noise ratio (SINR). Optimum combining is an IRC technique which has been presented in [5-6] and relies on the estimation of the channel gain of desired user and the covariance of the noise and interference. Because of the low distance between the transmitter and the receiver, the naturalistic body movements and the presence of a line of sight signal component in the on-body channels investigated herein, the receive branch antennas used for interference mitigation are prone to a more or less high correlation and power imbalance between the received signals, depending on the involved on-body channel. Because the OC does not take into account this correlation its performance in terms of interference rejection may degrade. Weiner-Hopf solution on the other hand relies on the calculation of the covariance between the reference signal and the received signal. This reference signal should be chosen carefully such that to be correlated with the desired signal but uncorrelated to the interference signal [6-7]. Thus it involves the estimation of the desired signal or something correlated to it, which is achieved by using a part of data for the training stage, thus reducing the data rate. In this paper, the performance of the Wiener-Hopf and optimal combining techniques in a multi-user environment is investigated.

The measurement campaign has been carried out at the laboratory university of Birmingham at the antenna and applied electromagnetics laboratory (AAEL) where the transmit and receive antennas of the desired user where mounted on a human body and the transmitting antenna of the interference signal was placed on another person's body. To encompass for links with different amount of statics and dynamics, two on-body channels were investigated namely the belt-head and belt-chest channels.

The paper is organized as follows. The measurement setup is presented in next section. The system model and a description of the interference cancellation techniques used in this work are given in Section III. The simulation results along with the analysis are provided in Section IV. Finally Section V gives the main conclusions.

2. MEASUREMENT SETUP

As mentioned above, the measurements were performed in the Birmingham university indoor laboratory environment, which dimensions were 7.5 m × 9 m and containing different equipment, tables, chairs, and computers. We are interested in the industrial, scientific and medical (ISM) band of 2.45 GHz. The transmit and receive antennas used on the desired user body were similar to the one mounted on the interferer body, i.e a microstip-fed planar inverted-F antenna (PIFA) on 0.8 mm thick FR4 substrate, with a ground plane and a substrate sizes of 45mm × 40 mm. The radiating plate was 1mm thick and the short-circuit and feeding pins were distant of 3mm. The coaxial cables used for measurements were fixed to the body such that to mitigate the effect of moving cables and maintain the distance between the body and the antennas at 7-10 mm including the clothing. Also, the antenna embedding loss was negligible since the return loss for all antennas once mounted on the body was still less than -10 dB at 2.45 GHz. The measured radiation patterns of the two PIFA elements when the other remaining ones are terminated by 50 ohms, are represented in Fig. 1 for the xy-plane.

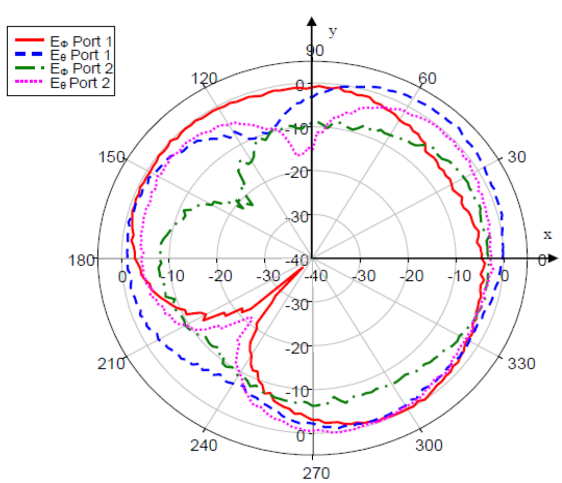

Figure 1. Radiation pattern of the PIFA element.

Two on-body channels were of interest: belt-head and belt-chest channels, where belt refers to the location of the transmit antenna while head, and chest indicate the location of the receive antenna array. The transmit antenna was placed on the left front side of the body at the waist position while the receive antenna on the desired user body was located at the right side of the head and the right side of the chest, respectively. The desired user and the interferer were randomly walking around each other in the room.

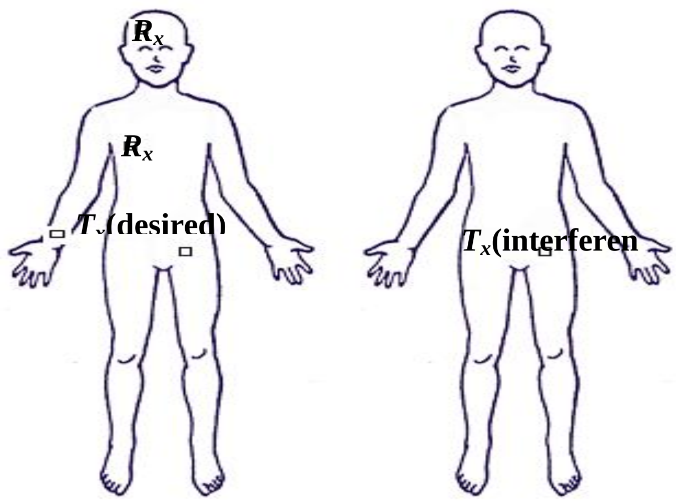

Figure 2 Placement of the antennas on the body.

The signal generator operating at 2.45 GHz was delivering the signal to the transmitting antennas of the desired and the interference users alternately via an RF switch which switching time was far below the coherence time of the channel [3-4]. The receive antenna was plugged to one port of a vector network analyzer (VNA) calibrated with a single frequency sweep at 2.45 GHz. The calibration was performed by connecting the signal generator to the used port of the VNA via the used cables, so that the total transmitted power was fixed at 0 dBm.
To guarantee perfect synchronization between the signal generator and the VNA validating the assumption of perfectly orthogonal CDMA users, the 10 MHz reference output signal of the signal generator was used. 800 samples from each of the desired user and the interferer were collected in the receive antenna, alternately through the switch, giving a total of 1600 points per 12 s sweep with a sampling time of 15 ms. A total of 6 such sweeps were repeated generating a data set of 4800 samples coming either from the desired or interference signals. The collected samples were the measured complex values of S21, thus containing both amplitude and phase of the channel attenuation.

3. INTERFERENCE CANCELLATION TECHNIQUE

The desired signal transmitting antenna is mounted on the same body as the receive antenna array to form an on-body channel while the transmitted interference signal comes from another BAN in the close vicinity. Thus the signal received at the ith branch of the N receive antenna array can be written as

$$x_i(t) = d_i(t) + i_i(t) + n_i(t) \qquad (1)$$

where di(t) is the received desired signal, ii(t) is the received interference signal, and ni(t) is the additive white Gaussian noise at the ith branch antenna.
Because of the constraining measurement setup, i.e the limited number of the VNA input and output ports and the limited length of the cables, a multi-user environment can hardly be characterized. Thus the simulation of a multiple access interference environment is performed in such a way that the channels of the desired user and one interferer are measured, then the channel of this interferer is characterized and its distribution is reproduced through simulations for all the remaining interferers assumed to be present in the indoor environment. Denoting the signal transmitted from the desired transmitting antenna as s(t), then

$$d_i(t) = H_i(t)s(t) \quad (2)$$

where Hi is the channel transfer function of the ith branch.
Denoting the received signal vector as X, with $\mathbf{X} = [x_1(t) \cdots x_N(t)]^T$ and the weight vector as W with $\mathbf{w} = [w_1(t) \quad \cdots w_N(t)]^T$, where [ ]T stands for the transpose of the vector, the array output, Y, is then

$$\mathbf{Y} = \mathbf{W}^T\mathbf{X} \quad (3)$$

In the optimum combining approach (OC), defining the interference signal vector at the N-receive antennas as $\mathbf{I} = [i_1(t) \quad \cdots i_N(t)]^T$, and the interference-plus-noise vector as U = I+N, the weight vector, W is generated as [6-7]:

$$\mathbf{W} = \mathbf{R}^{-1}\mathbf{H} \quad (4)$$

where H is channel transfer gain vector of the desired user and R is the so-called error covariance matrix which corresponds to the covariance matrix of U, i.e $\mathbf{R} = E(\mathbf{UU}^H)$, with (.)H representing the complex conjugate transpose of the operand and E(.) the expected value operator. U is estimated by using a training sequence [5-6].

The second approach investigated herein is the Weiner-Hopf solution of the weight vector which is calculated by using the covariance matrix of the received signal vector, $\mathbf{\Phi} = E(\mathbf{XX}^H)$, and the cross-correlation of the received signal X (t) and the reference signal Z (t)

$$\mathbf{W} = \mathbf{\Phi}^{-1}\mathbf{Z} \quad (5)$$

As mentioned earlier reference signal must be correlated to the desired signal and uncorrelated to the interference signal. In this work, the sum of the desired signals at the two receiving antennas is taken as the reference signal i.e.

$$z(t) = d_1(t) + d_2(t) \quad (6)$$

Conventionally, the weight vector as well as the corresponding covariance and correlation matrices are computed over a large set of the data over which the channel is stationary. The complexity is highly dominated by the calculation of the matrix inverse as given in (4) and (5), therefore by the data set size. In the approach presented in this paper, the algorithms are applied instead at each sample of the measured data and the corresponding weight vector is calculated. The calculation of the covariance and the correlation matrices in such a case is performed by using a local sliding window containing the previous samples of the current instant as well as the sample itself. For the first sliding window, the previous samples are obtained from a known training sequence, while for the remaining windows, the past samples are estimated from the received data.

Denoting the desired signal vector as $\mathbf{D} = [d_1(t) \quad d_1(t)]^T$, the input and output signal-to-interference-plus-noise ratio can be formulated respectively as

$$SINR_{in(i)} = \frac{|d_i|^2}{|i_i|^2 + |n_i|^2} \quad (7)$$

$$SINR_{out} = \frac{|W^T D|^2}{|W^T I|^2 + |W^T N|^2} \quad (8)$$

4. SIMULATION RESULTS

For the interference cancellation techniques, the respective weight vectors were calculated using either Eq. 4 or Eq. 5 for the OC and the WH solutions and the involved covariance and correlation matrices, namely R and Φ were computed using a local sliding window.
The mean powers of the desired and interference signals were evaluated and represented in table 1 along with the average ratio of the desired signal to interference denoted as SIR $_{avg}$ in the table. The high values of the powers for

the case of the belt-chest channel relative to the belt-head reflects the presence of a line of sight (LOS) signal. It is also seen that the SIR is higher for the best chest.

Table 1. Results for the two channels when using WH method and the number of users is 2

	Belt-head	Belt-chest
Mean power of desired signal s_1	-56.89	-37.67
Mean power of desired signal s_2	-59.87	-41.75
Mean power of interference signal i_1	-52.8	-51.36
Mean power of interference signal i_2	-60.10	-57.9
SIR_{avg} (dB)	4.67	18.27

The cumulative distribution function (CDF) of the output SINR was represented for the WH solution using different widths of the sliding window in the case of the belt-head channel in Fig. 3. It is seen that the output SINR is not that sensitive to the variation of the width of the window and the maximum loss in terms of SINR between the minimum and the maximum chosen values for the widths is slightly more than 2 dB.

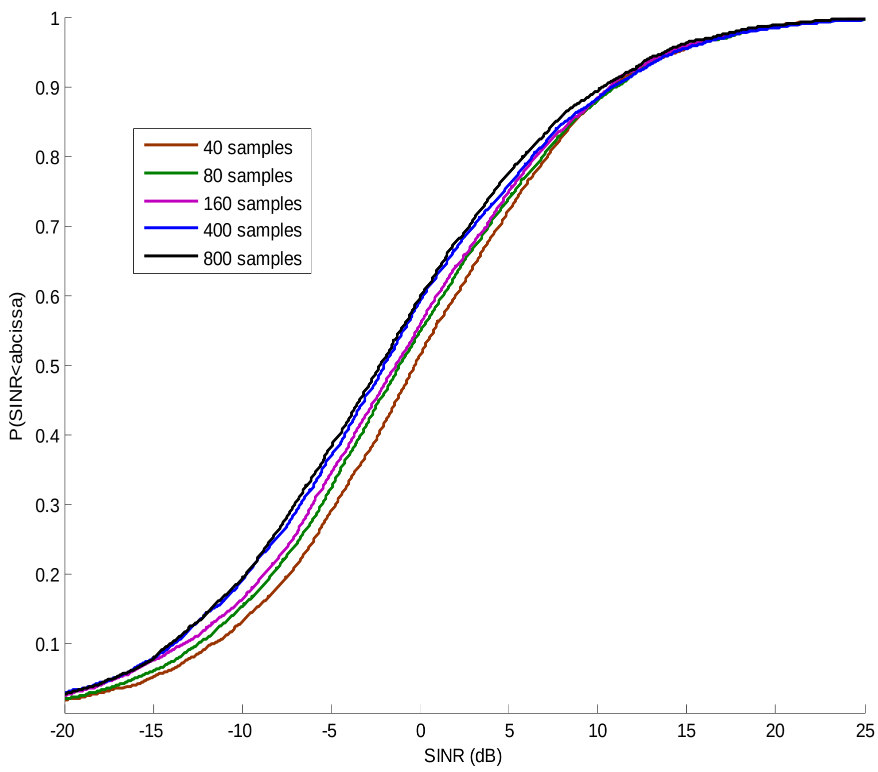

Figure 3. SINR CDFs for the belt-head when varying the width of the sliding window

When investigating the robustness of the belt-chest channel to the same variation of the window width, it is seen from Fig. 4 that it shows a considerable degradation in terms of the output SINR when increasing the window width and the maximum SINR loss is 7 dB. This is due to the fact that the sliding window changes the correlation among the signals at the antenna elements and since this correlation is high for the case of the belt-chest channel, it is the least robust to this variation.

The interference rejection gain (IRG) was calculated from the CDFs at 1% probability for each case and the results are presented in Table II.

It is shown from this table that the optimum combining is robust to the interference since the same IRG is noted when increasing the number of users from 2 to 20. This is due to the processing performed in OC technique which counteracts the effect of interference through the inversion of the error covariance matrix. The system incorporating the Wiener-Hopf (WH) approach sees its IRG degrades when increasing the number of interferers especially in the belt-chest case. This may be due to the effect of the correlation of the received signals at the two branches. Indeed, since the belt-chest is the on-body channel which shows the highest correlation degree among the received signals at the branches because of the presence of a high line of sight (LOS) component, the inversion of this correlation matrix as shown in Eq. 4 gives low values for the weigh vector resulting in low IRG for the channel.

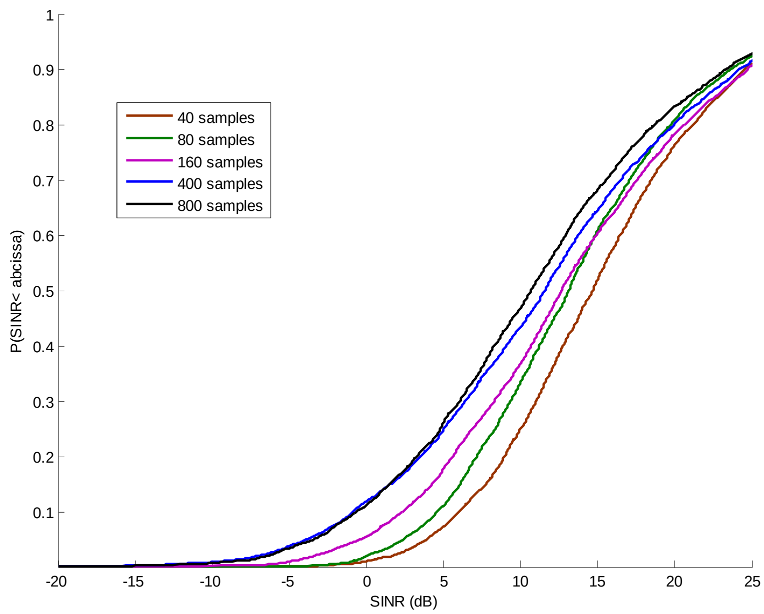

Figure 4. SINR CDFs for the belt-head when varying the width of the sliding window

The negative value for the IRG in this case means that the performance of IC techniques in this case is worse than the system without interference cancellation.

Table 2. Interference rejection gain

		Belt-Head	Belt-Chest
Wiener-Hopf	2 users	1.19	-2
	20 Users	-0.082	-4.35
Optimum combining	2 user 20 Users	4.55 4.55	-2.55 -2.55

The CDFs of the branch and the output signal-to-interference-plus-noise ratio are investigated hereafter in the figure 5 through 7. The output SINR in these figures has been calculated as

Figure 5. shows the SINR CDF for the belt head channel when using WH approach. It is shown that in the presence of two users, WH yields a positive gain over the strongest branch signal, while the performance in the presence of 20 users is poor and comparable to the weakest branch.

The same behavior is noted for the belt-chest channel using WH as shown in Fig. 6. When the number of users is 2, the performance of WH technique is overall slightly less than the strongest branch which is taken as a reference for the calculation of the IRG value. When the number of users is increased to 20, the performance of the IC technique using WF is close to the weakest branch, but since the power imbalance among the branches is high in such a case, it follows that the IRG is highly negative.

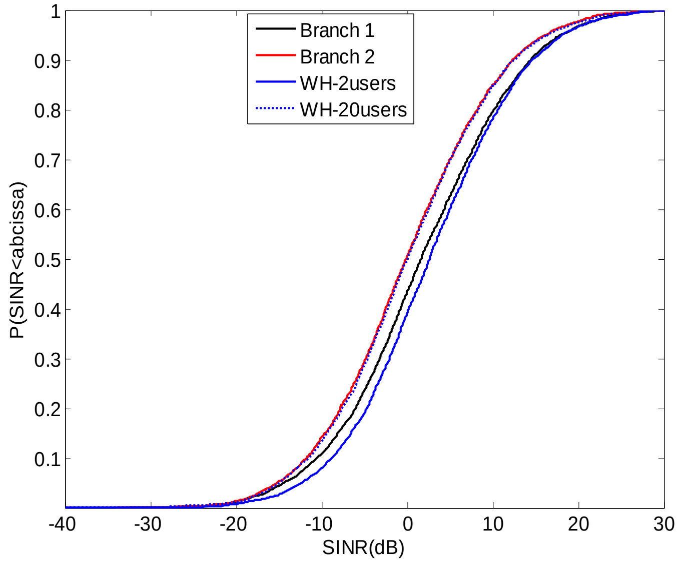

Figure 5. CDF of the SINR for belt head channel using WH approch

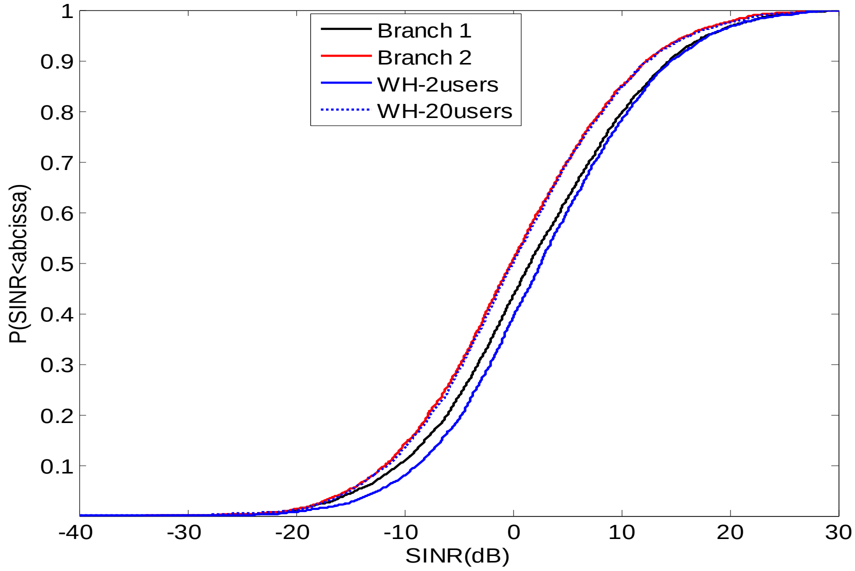

Figure 6. CDF of the SINR for belt chest channel using WH approach

Figure 7 depicts the SINR CDFs when using OC approach with both belt-head and belt-chest channels. It is shown that This technique is insensitive to the number of users to a certain level since the same performance is obtained with 2 and 20 users. The output SINR provided with OC is higher than the strongest branch for the belt head channel whatever is the probability level. For the belt-chest channel, at low probability the achieved SINR when applying OC to the system is less than the strongest branch which is behind a negative value for the IRG. When this probability increases, OC yields a better performance than the strongest branch

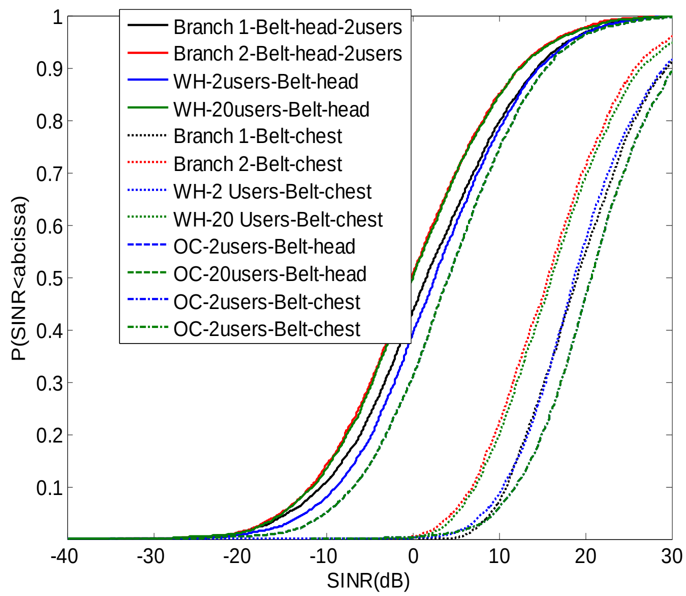

Figure 7. CDF of the SINR for belt chest channel using WH approch

5. CONCLUSION

In this paper, the interference rejection capability of the modified Wiener-Hopf and OC techniques using a sliding window for the calculation of the corresponding correlation and covariance matrices have been investigated. The investigated Wiener-Hopf modified approach does not yield a viable interference rejection capability in the case of the belt-chest channel unlike the belt-head channel which shows a higher robustness to the increase of the interference level. Optimum combining exhibits a higher interference rejection degree than Wiener-Hop and maintains a fixed IRG when increasing the number of interferers.

6. REFERENCES

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