Interference in Body Area Networks: Distance does not dominate

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***Abstract*—Inter-network interference is a significant source of difficulty for wireless body area networks. Movement, proximity and the lack of central coordination all contribute to this problem. We compare the interference power of multiple BAN devices when a group of people move randomly within an office area. We find that the path loss trend is dominated by local variations in the signal, and not free-space path loss exponent.**

I. Introduction

Wireless Body-Area-Networks (BANs) represent the next generation in personal area networking [1]. The IEEE-802.15.6 group has provided details of the expectation of such networks. The requirements [2] include data rates from 10kbps to 10Mbps, an operating range of 3m (6m×6m×6m volume), up to 10 co-located networks each with up to 256 nodes. The potential for co-channel interference – *from other BANs and also from other interferers* – in such networks is large.

Previous work on pico-cells has considered the effects of WiFi/WLAN on both ZigBee [3], [4] and Bluetooth [5] networks. In all cases, the authors concluded that 2.4GHz ISM interference could substantially reduce the performance of low-power personal area networks. Interference has also been cited as a concern for security of BANs [6], [7].

In cellular- and sensor- networks, interference is well understood (although still an active area of research). Interference mitigating systems have been widely proposed [3], [8], [9] largely based upon CDMA techniques, and/or specific shutdown mechanisms for TDMA [10].

A body area network comprises a (potentially large) number of nodes located on a single user communicating with a local co-ordinator. It is expected that BANs will not co-ordinate between networks – ie, the network on one person will be unable to co-ordinate with the network on someone else. This is because there is no natural choice of co-ordinator, there is no master clock (between networks). As the user moves, the whole network moves and may move into (and out of) range of other networks quickly. We refer to this event as a *network collision* [11]. It is different to the interference events of cellular- or sensor- networks where only one or two nodes interfere, *and base-stations rarely interfere*. The random nature of movement means that network collisions may be very short – people passing on the street – or very long eg. family members or hospital patients may remain close for hours [11].

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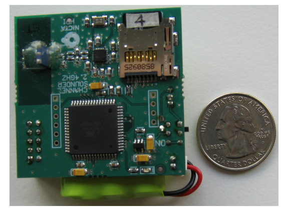


Fig. 1. Wearable channel sounder, at 2400MHz ISM band. US quarter shown for scale, PCB is approx 50mm×40mm.

Sensor net approaches such as power control [12] or sensor scheduling [13] do not apply – as all the BAN nodes may be experiencing interference.

The mobile and variable nature of BANs means that a cellular approach [14] cannot be applied to combat interference. Fundamentally the concept of a "distance to interferer" or a local cell for a BAN node does not apply. BAN radio propagation is dominated by local variations and not by distance-based path losses. We have demonstrated the variability for single user BANs [15], [16]. In this paper we examine the variability of interference signals with respect to distance. Some recent work had considered path loss in person-to-person measurement campaigns [17], [18]

II. Experiment setup

A. Radio considerations

The interference is measured via a wearable channel sounder, which measures the received signal strength indicator (RSSI) of its operating channel. The transceiver is shown in Fig. 1. Each transmitter sends packets with a transmit ID attached. When a channel sounder device receives a packet from another device it logs the packet ID and RSSI: the ID provides the link identification and the RSSI provides the instantaneous signal strength for that link. Signal-to-Interference (SIR) is found by declaring a given link to be a reference, and other links to be interference. In a BAN the *signal* link is on-body (ie. between one device on a person and another device on the same person) while the *interference* link is off-body (ie. from a device on another person).

The sensitivity of the transceiver is -95dBm, and any packet received with a signal strength below this value is dropped. Multi-path (symbol self-interference) is negligible for the narrow bandwidths considered [16].

Subject	1	2	3	4	5
Tx	(1) right hip	(2) right hip			
Rx	(a) right shoulder	(b) left wrist (f)* right hip	(c) left hip	(d) left hip	(e) left hip

TABLE I
SENSOR PLACEMENT FOR INTERFERENCE MEASUREMENT. *SUBJECT 2 TRANSMITTER ALSO RECEIVED PACKETS: (2) AND (F) ARE CO-LOCATED.

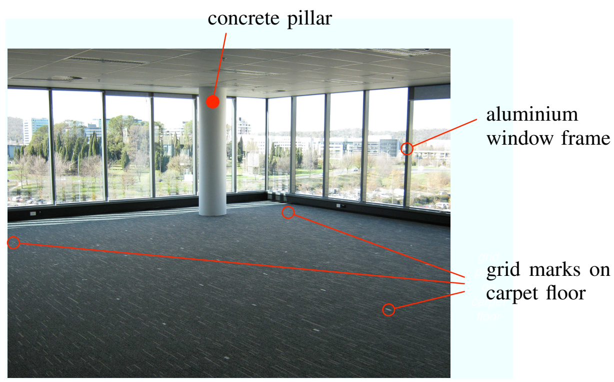


Fig. 2. 6m×6m grid arrangement in large open-plan indoor environment. Experiment conducted at NICTA, Canberra Research Lab office, level 5.

The transceiver was tuned to 2,360MHz in order to avoid unnecessary interference from local WiFi sources. The experiment used a fixed transmit power of 0dBm for all transmitters.

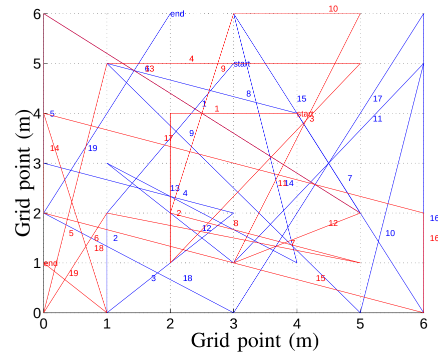
B. Experimental arrangement

The experiment was carried out in the NICTA, Canberra Research Lab, top floor which is open plan, on a 6m×6m grid, marked out on the carpet floor. The physical setting is shown in Fig. 2. The experiment used 5 (male 22yr-35yr) subjects moving in a pseudo-random walk on the grid.

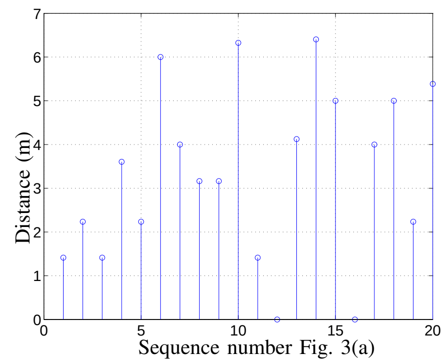
The pseudo-random walk was generated by selecting an x-grid point $x = \{0, 1, 2, 3, 4, 5, 6\}$ and a y-grid point $y = \{0, 1, 2, 3, 4, 5, 6\}$ independently, uniformly at random, and independently for each subject. For each (x, y) grid location the subject walked directly from their previous location, during an interval or 5 seconds, and then remained stationary at location (x, y) for 15 seconds.

The transceivers were placed on various locations on the subjects as shown in Table I. Two links 1a and 2b were used as reference signals, while the 3 receivers on the remaining subjects measured interference. The reference links were on-body-to-on-body, whilst the interference links were on-body-to-off-body.

Link RSSI measurements were made for links 1a, 1b, 1c, 1d, 1e, 1f, 2a, 2b, 2c, 2d, 2e. Using reciprocity we reverse the link measurements 1a–1f and 2a–2e to give the interference experienced at 1 and 2. (ie, whilst we physically *transmit* from 1 and *receive* at a-f we may interpret the result as *transmit from a-f* and *receive at 1-2*. This approach ensures the multiple



(a) Movement trace



(b) Distance subject 1 to subject 5 vs sequence number

Fig. 3. Experiment trace for two subjects (red = subject 1 and blue = subject 5 from Table I) moving in pseudo-random walk over a 6 × 6m grid with 1m gradation. Numbers correspond to the sequence of the random walk (ie, start → 1 → ··· → 20 → end.) Subjects walked along lines (shown) for 5sec, and stood at grid points for 15sec in each 20sec period. Grid point $(0, 0)$ in Fig. 3(a) corresponds to the far corner in Fig. 2.

network packets remain time-synchronized. The link strength measurements were taken simultaneously for all 10 links every 10ms.

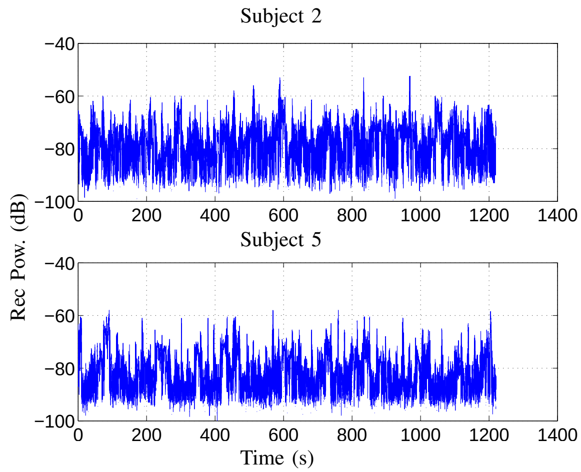
III. ANALYSIS

A. Use the median for signal characterisation

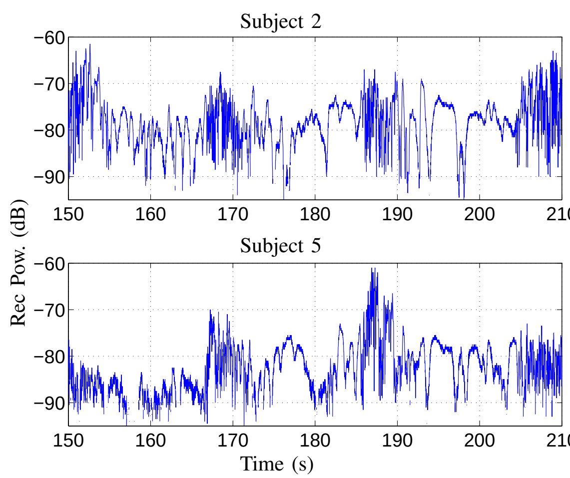
From our work [19] we find the median of received power (in dB or linear) is a better representation of the true operating point of the system. The signal power is better characterised by the median, rather than the mean, as the mean is dominated by outliers. The mean gives artificially high results in when calculated using linear values and artificially low results in when calculated using dB values. This is due to the high variance of the channel: for a mean, in a linear scale the (very) low fades are dominated by high signal values, while for logarithm scale the reverse occurs. The median value is not dominated by such outliers.

For a statistical signal x the median $\mu_{1/2}(x)$ is an optimal estimator for absolute error:

$$\mu_{1/2}(x) = \arg\min_{c} E\{\|x - c\|\} \qquad (1)$$

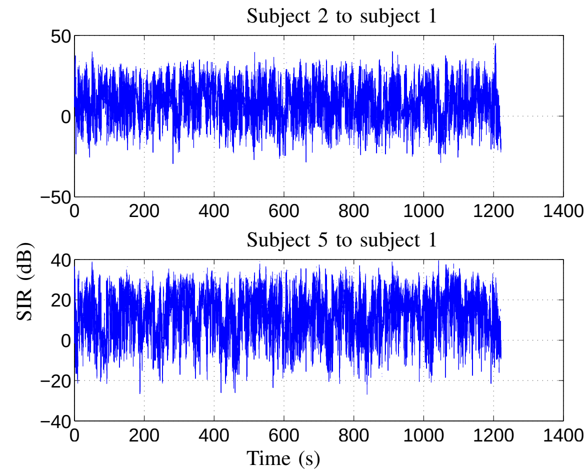


(a) Subjects 2, 5 interference power received at subject 1

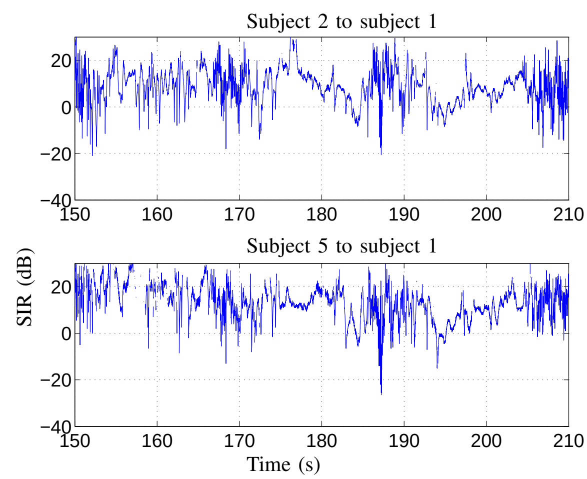


(b) Zoom view (60sec)

Fig. 4. Interfering signal strength measured at subject 1, from subjects 2 and 5 over full experiment and over a 60sec snapshot



(a) Subject 1, SIR, due to subject 2, and subject 5



(b) Zoom view (60sec)

Fig. 5. Signal-to-inteference ratio at subject 1, with subjects 2 and 5 interfering, over full experiment and over a 60sec snapshot

The median is used when outliers are less important [20]: a fade of 30dB is not significantly different to a fade of 100dB since any degradation has already occurred. We also have the functional relation; for a function $f(x)$, $f(\mu_{1/2}(x)) = \mu_{1/2}(f(x))$: if we measure the signal in dB, we may calculate the median directly without needing to accommodate a change of derivative (due to change of expectation variable).

B. Distance vs Interference Power

All devices maintain constant transmit power, hence the variation in received power at a subject is due to

1) Free space path loss (D^n, $n \geq 2$)
2) Shadowing due to orientation/movement of people

Figure 4 shows the received interference power from 2 subjects, measured at subject 1. This is shown for the full 20minute experiment in Fig. 4(a) and a 60sec snapshot in Fig. 4(b). The received signal is between -60dB and -100dB for the whole experiment. However, since the link on subject 1 also has a low signal power, the SIR varies between large values (+40dB) and small values (-40dB). We highlight this in Fig. 5 which shows the SIR due to subjects 2 and 5 at subject 1. This is shown for the full 20minute experiment in Fig. 5(a) and a 60sec snapshot in Fig. 5(b). It can be seen in Fig. 5(b) that the interferers are often substantially more powerful than the reference link. This result is caused by the shadowing of the human body which absorbs approx. 60dB power — free space losses are much lower, and hence depending on the orientation of the reference and interfering subjects the interferer may have a clear line-of-sight to the receiver while the reference link does not.

The median SIR for subject 1 is given by Table II. This value provides an indication of the operating severity of the various links, but should be considered with care since the subjects were confined to a 6m square, and the SIR values are a non-stationary sequence.

C. Median trend analysis

We removed the component of the measurements corresponding to each 5second walking interval. The walking intervals resulted in substantially larger variation in signal

Subject	1	2	3	4	5
median SIR (dB)	$\star$	(b) 9 (f) 6	7	7	13

TABLE II
MEDIAN SIR FOR 20MINUTE EXPERIMENT MEASURED AT SUBJECT 1

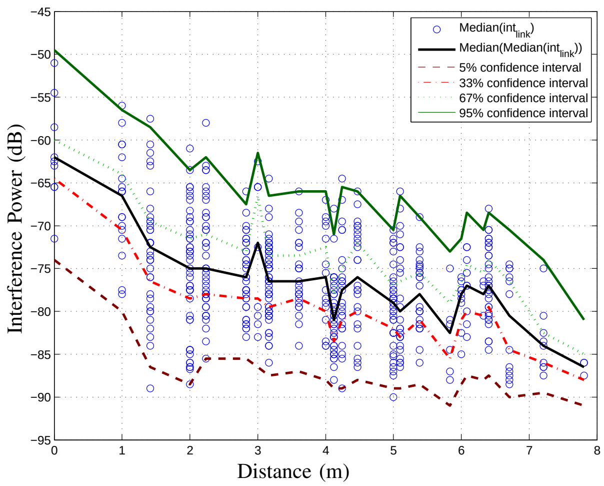


Fig. 6. Median interference power received from subjects compare with free-space distance between subjects.

strength, and are (obviously) not strongly correlated with relative subject distance. The effect of walking may be observed at approx. 150sec, 170sec, 190sec and 210sec, and is shown for reference in Fig. 4(b) and Fig. 5(b).

Fig. 6 shows the median received interference power for each link $\mu_{1/2}(\text{int}_{\text{link}})$ for the experiment with upper and lower confidence intervals. The plot show median values for 9 links $\times$ 60 positions from the random-walk. The overall linear trend for $\mu_{1/2}(\text{int}_{\text{link}})$ is given by

$$\mu_{1/2}(\text{int}_{\text{link}}) = -2.1 D_{\text{metres}} - 67.7 \quad \text{dB} \tag{2}$$

The macroscale free-space path-loss with a shadowing loss for the human applies. However, the variation of the results is significantly larger than the trend — it can be seen that the median operating point for 0m (-67.7dB) is still within the 95% confidence interval at 6m — double the range of the BAN. This implies that results which rely on a linear free space path-loss model will be highly susceptible to reasonable human movements.

IV. CONCLUSIONS

We have measured the signal-to-interference ratios and interference-power levels for a pseudo-random walk of 5 subjects in an indoor area. We have found that a linear trend may be applied to the interference signal power, but the trend is dominated by factors which are not related to distance. The "non-distance" factors include subject movement – both local such as arm waving and global such as walking – and orientation. We have shown that the signal-to-interference ratio may be low or even negative over the course of the experiment.

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