AN INVESTIGATION OF COOPERATIVE TRANSMISSION APPLIED TO AGRICULTURE

Mary Ann Ingram[†], Mayuri Prasad[‡], Aravind Kailas[†], and Ramjee Prasad[‡]
[†]School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA
Department of Communication Technology, Aalborg University, Aalborg, Denmark

***Abstract* - This paper considers the application of wireless sensor network technology to biosensing in farm animals. Biosensing can help farmers detect contagious disease in its early stage before it spreads to others, reduce stress in cows to improve their milk production, and detect the time of ovulation for artificial insemination in animal breeding programs. Implanted sensors have the benefits of accuracy in measurements and low maintenance, but current technology has very short range. In this paper, we propose the use of a two-hop wireless transmission protocol where the sensors implanted in animals (for example, cows) cooperate to relay information to a remote access point. The protocol is based on a type of cooperative transmission called opportunistic large arrays (OLAs). Analysis using Monte Carlo simulations and assuming path loss, lognormal shadowing, and radio link parameters consistent with the Medical Implant Communication System (MICS) standard, shows the potential of this strategy for enabling long-range transmission directly from implants in herd animals without requiring high transmission powers.**

1. INTRODUCTION

Biosensing in farm animals has many potential applications and is being considered by several research groups. The use of biosensors in agriculture sector can considerably improve animal health and welfare [9] along with ensuring meat quality and increasing production. Biosensing can help farmers detect contagious disease in its early stage before it spreads to others [9], reduce stress in cows to improve their milk production, and detect the time of ovulation for artificial insemination in animal breeding programs [8].

Most sensors in use today are not implanted. The drawback of using external sensors is that they are prone to wear and tear due to animal activity and exposure to the outside environment and also that they cannot give accurate measurement. Implanted sensors have the advantages of better measure-ments, more stable environment, and lower main-tenance. Wireless sensor implants are being considered for monitoring physiological parameters such as core body temperature [10,11]. However, these have the disadvantage of a radio transceiver being mounted on the collar, to receive the signals from the implants and relay them to a distant receiver. Such transceivers may be too expensive to put on every animal in a herd and are vulnerable to harsh environments.

In this paper, we consider how a simple two-hop cooperative transmission method might enable communication between implanted biosensors in a herd of animals to an access point, say, at the edge of a field. This is an example of the long-studied *reach back communication problem* [1,3]. We apply a concept called the opportunistic large array (OLA) [2], where a number of sensors implanted in other animals help by relaying the signal transmitted by the sensor in one animal. The relays operate without any mutual coordination, but naturally fire together in response to energy received from the source. In this way, the transmit power in each implant is kept very low, but the collective signal is strong enough and has enough diversity to enable its reception at a relatively long distance away by the sink node. We compare the total transmit power expended by the cooperative transmission network compared to the power that would be required for a single hop (i.e. directly from the source to the sink) to have the same reliability.

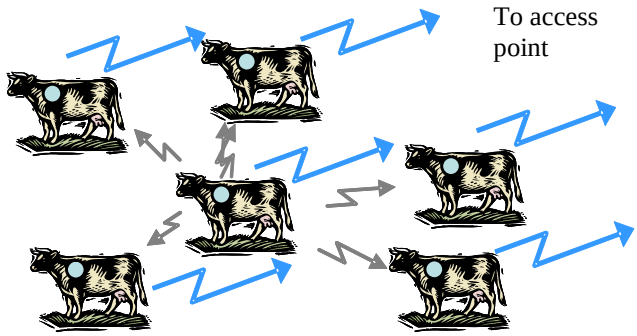

Figure 1. Two-hop cooperative transmission from sensors in a herd of cows.

2. MODELING ASSUMPTIONS

We evaluate a sensor network where each sensor node is implanted in a different individual (e.g. a cow), and the individuals are uniformly distributed over a disk. The objective is for the message from an implanted sensor in the center of the disk to reach the sink that is some distance away from the disk, but on the same plane as the disk

The network architecture is shown in Fig. 2. Half-duplex nodes are assumed to be distributed uniformly and randomly over a disk of radius R_C. The source node is assumed to be in the middle of the disk. The access point or base station (i.e. the sink) is a distance d away from the source. The power model [4] is assumed, which means that the power received at the sink is the sum of the powers from each of the relay transmissions. This

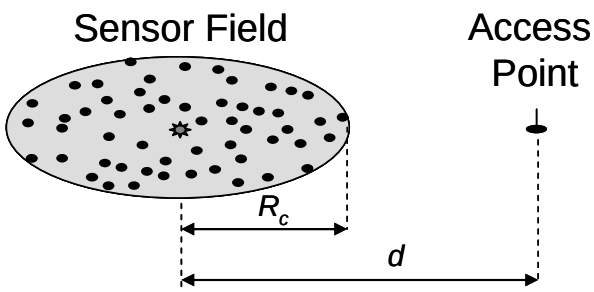

Figure 2. The planar reach back network architecture. The source is indicated by the starred sensor in the center of the field.

model implies the transmissions from each sensor are orthogonal to each other and can be recovered separately by the sink node. We expect that in a realistic scenario, a desired number of orthogonal dimensions can be created by relays appropriately offsetting their transmissions, for example, in delay [5]. Every wireless channel between a single transmitter and a single receiver is assumed to suffer free-space path loss and independent lognormal shadowing with parameter σ; this includes the links from the source to the relays (other sensors) and from the relays to the sink. Multi-path fading is ignored.

The radio parameters are taken from [6], which assumes the Medical Implant Communication System (MICS) standard [7] and propagation from implants in humans to collection antennas several meters away. To the best knowledge of the authors, reference [6] is the only propagation study that assumes implanted sensors and a sink in the far field away from the body.

The MICS standard is designed for short range radio transmissions that will not interfere with other applications in the same band. Therefore, MICS is not intended for long range transmission, so using it to achieve long range connectivity (as we have analyzed) is not possible. Also, propagation parameters for animals are likely to be different than for humans. However, using practical values for variables such as TX power, body attenuation, and receiver noise, this analysis is a start to demonstrate the potential gains of OLA two-hop transmission relative to single-hop transmission.

The parameters assumed in the study, common to all cases considered, are shown in Table 1. These parameters, except for bandwidth, SNR threshold, and lognormal shadowing, were taken directly from [6]. The bandwidth, 250 KHz, is one of the bandwidths considered in [6]. The 8 dB shadowing standard deviation is based on the recommended margins in [6] of between 7 and 14 dB to account for body size, orientation, and arm movement. The SNR threshold of 5 dB was considered to be reasonable for a low data rate with coding. An additional contributor to shadowing in the farm animal application is expected to be other animals blocking the link between a transmitter and a receiver.

3. PRELIMINARY RESULTS

Our general analysis approach was the following:

1. Set the implant transmit power at -2 dBm [6].
2. For a given R_C and number of relays, N_S, find the range *d* that achieves approximately X% outage to the base station for the two-hop cooperative transmission method using Monte Carlo techniques.
3. Compute the total transmit power of the cooperative transmission network for that range, by adding the powers of the source and all the relays.
4. Using theory, calculate minimum source transmit power, "min $P_{1\,hop}$ required," to achieve the same X% outage for a single hop.

In this abstract, we consider the three cases defined in the first four columns in Table 2. The 'high density high reliability' (HDHR) case has 100 nodes spread over a disk of radius 20 m with a required outage rate of just 3%. The other cases are 'low density high reliability' (LDHR) and 'low density low reliability' (LDLR).

Table 2 also shows some results from our analysis. We observe that for the three cases respectively, the outage rates of 3%, 4%, and 30% produced ranges of 200m, 40m, and 120m. As one might expect, the HDHR case, with its large number of relays (because of the high density) and the corresponding large number of macro-diversity channels in the second hop, produced the highest source (implant) transmit power requirement of 25.6 dBm for the single hop. This can be compared to -2 dBm implant transmit power assumed for the cooperative transmission case. For the LDHR case, the minimum required implant transmit power, to achieve the outage of 4% at the shorter range of 40m, is 10.4 dBm. This is still significantly higher than the -2 dBm required for cooperative transmission. If we allow the higher outage rate of 30%, but keep the other parameters the same as the LDHR case, then the range grows to 120m and the minimum required single-hop implant transmit power is still higher at 10.3 dBm.

Table 1. Parameters that are Common in the Cases Studied

Description	Value
Number Monte Carlo trials	5000
SNR threshold	5 dB
Path loss exponent	2
Receiver noise spectral height (kT)	-174 dBm/Hz
Noise Figure of implant	9 dB
Noise Figure of access point	4 dB
RF frequency	402 MHz
Receiver bandwidth	250 KHz
Lognormal shadowing parameter	8 dB
Gain of implant antenna + body	-33 dBi
Gain of access point antenna	2 dBi

Table 2. Parameters that Differ in the Cases Studied, and the Required Single-Hop Power

Case	R_c (m)	N_S	OR (%)	*d* *(m)*	min P_{1hop} required (dBm)	$E\{P_{1hop}\}$ (dBm)
HDHR	20	100	3	200	25.6	10.5
LDHR	40	80	4	40	10.4	-3.4
LDLR	40	80	30	120	10.3	6

We expect the OLA cooperative transmission approach to produce array gain and macro-diversity gain. The array gain comes from the simple addition of powers from each of the relays, and therefore depends on how many sensors relay. The macro-diversity gain comes from the multiplicity of independently shadowed links in the second hop. Therefore, the number of decoding sensors and the SNR received at the access point to be correlated.

Fig. 3 shows a scatter plot of these two parameters for the HDHR case and indicates a moderate positive correlation. Recall that the number of sensors in this case is 100. The distribution indicates that in most trials, the number of sensors that relay ranges between 10 and 30 and the SNR received is between 10 and 25 dB. Fig. 4 shows the scatter plot for the LDHR case; the number of decoding nodes is considerably lower (because of the low density) and there is still a positive correlation.

One might think that the cooperative transmission approach would use more total energy compared to the single-hop case because so many more nodes are transmitting, however, this is not the case. Figs. 5 and 6 show the cumulative distribution functions (CDFs) for the total transmit power of the cooperative transmission approach, for the HDHR and LDHR cases, respectively. We observe in Fig. 5 that the highest total power in the distribution is only around 13 dBm; this is still less than the 25.6 dBm required for the single-hop case. The mean implant transmit power for single-hop is shown in last column of Table 2. For HDHR, this is 10.5 dBm. That this is close to the median in Fig. 5, but much less than 25.6 dBm is an indication of the macro-diversity gain provided by the cooperative transmission approach.

Fig. 6 shows the CDF for the LDHR case, indicating a maximum total transmit power of around 9 dBm. That this is only slightly lower than the minimum required implant power of 10.4 dBm shows that the gap in total required power closes when the network density decreases.

5. CONCLUSIONS

These preliminary results show that two-hop OLA cooperative transmission shows promise for enabling long-range transmission directly from implants in herd animals without requiring high implant transmission powers. While it is true that there will be many more transmissions with the OLA approach than with single hop, the OLA approach should be safe for the animal as long as the rate of transmissions is low enough for any heat generated to be dissipated. Future efforts will include the more practical modeling aspects of multi-path fading and limited numbers of orthogonal receive channels. The impact of these modeling additions is not clear as more fading will favor the OLA approach, while limiting the number of diversity channels, will tend to close the gap.

ACKNOWLEDGEMENT

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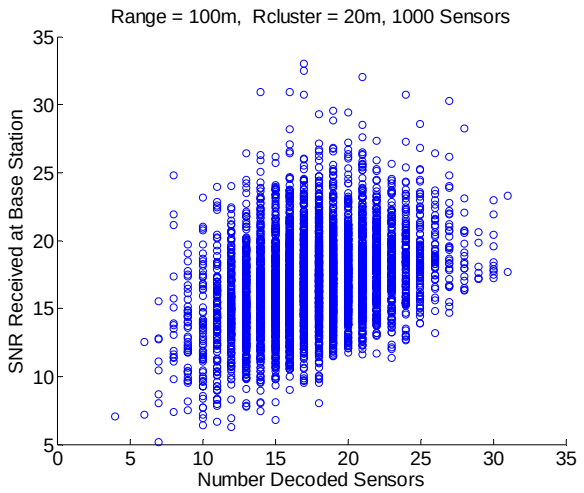

Figure 3. High density high reliability: scatter plot of SNR received vs. the number of relays.

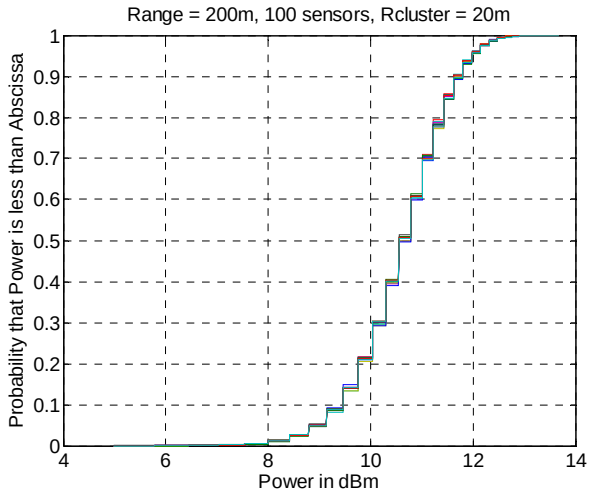

Figure 5. High density high reliability: CDF of the total transmit power for cooperative transmission for the range that achieves 97% reliability (200m).

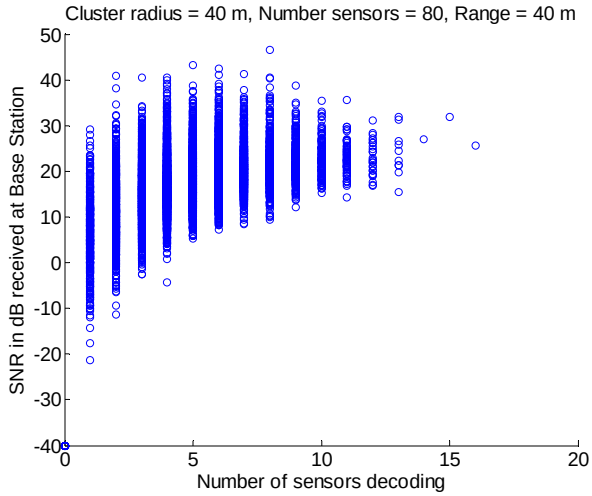

Figure 4. Low density high reliability: scatter plot of SNR received vs. the number of relays.

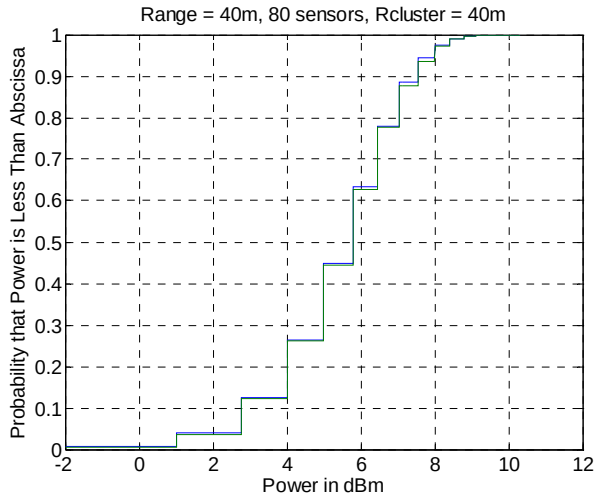

Figure 6. Low density high reliability: CDF of the total transmit power for cooperative transmission for the range that achieves 96% reliability (40m).