Power Control with MIDRS Codes in VMIMO WSN using Game Theoretic Approach

R.Valli, P.Dananjayan

Abstract— ***Improvements in electronic and computer technologies have tiled the path for explosion of wireless sensor networks (WSN). A fundamental component of resource management in WSN is transmitter power control and an efficient power control technique is essential to support system quality and efficiency. The data transmitted from the sensor nodes is highly susceptible to error in a wireless environment which increases the transmit power. Error control coding (ECC) schemes can improve the system performance and has an impact on energy consumption. Further the adverse impacts caused by radio irregularities and fading increases the energy consumption and thereby reduces the WSN lifetime. To reduce the fading effects in wireless channel, multi-input multi-output (MIMO) scheme is utilised for sensor network. This paper proposes a power control solution considering Multivariate Interpolation Decoding RS (MIDRS) Code in Virtual MIMO (VMIMO) WSN using game theoretic approach. The game is formulated as a utility maximizing distributed power control game while considering the pricing function. VMIMO utilising space time block code (STBC) along with MIDRS code enables to achieve higher energy savings and longer network lifetime by allowing nodes to transmit and receive information jointly. The performance of the proposed power control scheme with MIDRS code for the virtual MIMO wireless sensor network is evaluated in terms of utility, power efficiency, energy consumption and network lifetime.***

Index Terms— ***Game theory, MIDRS code, Space time block code, Virtual MIMO, Wireless sensor network***

I. INTRODUCTION

Wireless sensor networks (WSN) are widely used in diverse areas of applications including surveillance, intrusion detection and environmental monitoring. The size of sensors is typically small, and the operations rely on batteries which is difficult to replenish or recharge in most applications[1]. As a result, energy efficiency is critical in WSNs. Among various resource management methods power control in WSN is significant to overcome unnecessary interference and save the battery life of the sensors. The design of agile power control algorithms for wireless sensor networks is decisive to reduce energy consumption to a level appropriate for many applications. This is for instance the case in the disaster relief scenario, where wireless sensor nodes are used to provide real-time information on the physical conditions in a militaryenvironment. In such a circumstance, where recharging is typically not possible, radio power control is vital in order to increase the network lifetime.

As sensors are used for high end applications, the data has to be reproduced with extremely low bit error rate (BER). To maintain the BER within a limit, either transmit signal power has to be increased or error control coding (ECC) can be used. ECC reduces the required transmitted signal energy because of its coding gain. Energy constraint transmission issue of WSN makes forward error correction (FEC) a popular error correction technique to be used in such networks reducing the frame error rate and consequently the number of retransmissions. A system with FEC can provide reliability using less power than a system without FEC [2]. Therefore proper error control coding can save the power required for communication of the information bits.

Game theory has been effectively used in ad hoc and sensor networks for designing mechanisms to provoke desirable equilibria by contributing incentives to the forwarding nodes [3-6]. This economy based model is adopted for power control of WSN and a game model can be designed by particularly considering the benefits of ECC in a WSN.

Multipath fading strongly impacts the communication and increases the possibility of signal cancellation which leads to higher packet loss and therefore resulting in more power consumption in wireless environments. MIMO technology has the potential to enhance channel capacity and reduce transmission energy consumption particularly in fading channels [7,8]. This is done by exploiting array gain, multiplexing gain and diversity gain. However, direct application of multi-antennas to sensor nodes is not viable due to the restricted physical dimension of a sensor node which typically can only prop up a single antenna. If individual nodes cooperate for transmission and/or reception, a cooperative MIMO system can be build such that energy-efficient MIMO schemes can be employed in WSN. Cooperation among sensor nodes termed as virtual MIMO (VMIMO) has the ability to reduce the total power consumed for data transmission in the sensor network. In this paper, game theoretic formulation for power control in VMIMO WSN along with MIDRS code is done.

The rest of the paper is organised as follows. Section II, deals with MIDRS coding for WSN. The power control game considering VMIMO scheme with MIDRS code is formulated in section III. Simulation results are given and discussed in section IV. Finally, conclusions are drawn in Section V.

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II. ERROR CONTROL CODING FOR WSN

A. *Multivariate Interpolation Decoding RS (MIDRS) code*

In MIDRS [9], *M*-RS codes are transmitted together and decoded using (*M* + 1) variate interpolation. The encoding is of complexity order of *M*-RS encoders. The MID algorithm attempts to list-decode up to

$$t_{MIDRS} = Mn_{RS}\left(1-\frac{k_{RS}}{n_{RS}}^{\left(\frac{M}{M+1}\right)}\right) \quad (1)$$

where t_{MIDRS} is the maximum number of correctable errors for MIDRS.

The advantages of multivariate interpolation algorithm are that the error-correction radius t_{MIDRS} of the MID algorithm is greater than t_{RS} of RS code for all rates. While the Bleichenbacher, Kiayias, and Yung (BKY) and by Coppersmith and Sudan (CS) decoders of RS codes simply fail for certain error patterns, the MID algorithm offers a graceful degradation option. The probability of decoding failure is significant for the CS decoder, but it is often negligible for the MID algorithm.

For PSK modulation BER is expressed as [10]

$$BER_{coded} = \frac{1}{n_{MIDRS}} \sum_{j=t_{MIDRS}+1}^{n_{MIDRS}} \binom{n_{MIDRS}}{j} j(1-p_c)^{n_{MIDRS}-j} p_c^{\,j} \quad (2)$$

where,

n_{MIDRS} is the length of the code word for MIDRS,

k_{MIDRS} is the number of information symbols for MIDRS,

p_c is the channel symbol error probability

III. GAME THEORETIC APPROACH

Game theory provides a suite of modeling tools for analyzing interactive scenarios and strives to predict their possible outcomes[11,12]. It can be applied to the modeling of a sensor network at the physical layer (distributed power control), link layer (medium access control) and network layer (packet forwarding). Formally, a game has the following three components:

- The set of players, $N = \{1,2,3\ldots,n\}$
- The set of actions, A_i, available for a player *i* to make a decision.
- The payoff function resulting from the strategy profile.

One of the goals of game theory is to predict the likely outcome of a game. The Nash Equilibrium (NE) is the most well-studied and generalized solution concept in game theory. An NE is a stable point from which no rational player has any incentive to unilaterally alter his action. Therefore, in some sense, an NE is a consistent predictor of the outcome of a game.

A. *Game Theoretic Approach for Power Control*

The model considered consists of N nodes in the network. Low-Energy Adaptive Clustering Hierarchy (LEACH) [13] application-specific protocol architecture is exploited in the cluster formation phase. Any node which senses information transmits the data to the cluster head (CH) within its cluster. The cluster head through local communication broadcasts the data to M_t active nodes which compose the distributed antenna array. The active nodes are a subset of the total cluster nodes. At this step each node in the transmitting cluster has data and encodes the transmission sequence according to Space Time Block Coding (STBC) along with MIDRS code as if each node were a distinct transmit antenna element in the centralized antenna array. This set of M_t cooperative sensor nodes, communicates with the receiver cluster composed of an active set of M_r cooperative sensor nodes. The receiving cluster receives data through an $M_t \times M_r$ MIMO channel.

Space time coding schemes are used to improve the performance of MIMO WSN by combating the channel fading and interference. The code provides the full diversity over fading channels and improves the quality of signal transmission. Of the space time coding schemes, STBC[14] is more suitable for wireless sensor network with low encoder/decoder complexity.

The nodes in the network play repeated game. The information from earlier rounds are used to work out strategies in upcoming rounds. All the nodes can transmit with any power level to make its transmission successful. Also, the nodes have no information if the other nodes are transmitting, hence leading to an incomplete information situation. If the nodes transmit with an arbitrary high power level, it will increase the interference level of the other nodes. The neighboring nodes in turn will transmit at higher power to overcome the effect of high interference. Soon, this will lead to a non cooperative situation. To control this non cooperative behavior, an equilibrium game strategy which will impose constraints on the nodes to act in cooperative manner even in a non cooperative network is devised.

The subsistence of some strategy sets $S_1, S_2, \ldots, S_x$ for the nodes 1, 2, . . . , (x) is assumed. These sets consist of all possible power levels ranging from the minimum transmit power s_{max} to maximum transmit power s_{max}. In this game, if node 1 chooses its power level, $s_1 \in S_1$ and node 2 chooses its power level $s_2 \in S_2$, and so on, then the set of strategies chosen by all x nodes is given by [12],

$$s = \{s_1, s_2, \ldots\ldots s_x\} \quad (3)$$

This vector of individual strategies is called a strategy profile. The set of all such strategy profiles is called the space of strategy profiles S′. The game is played by having all the nodes concomitantly choose their individual strategies. This set of choices results in some strategy profile $s \in S$, and is called as the outcome of the game.

$$u_i(s) = u_i(s_i, s_{-i}) \quad (4)$$

s_{-i} is the strategy profile of all the nodes but for the i^{th} node. The utility to any one node depends on the entire strategy profile. During every game, the node decides whether to transmit or not, rise or lower its power level, and chooses a power level if it decides to transmit. The utility of the game considering VMIMO scheme is given as [15]

$$u_i(s_i, s_{-i}) = \sum_{j=1}^{M_R} \frac{LR}{F \sum_{i=1}^{\min(M_T,M_R)} \frac{s_i}{\min(M_T,M_R)}} f^c(\gamma_j) \quad (5)$$

where

L is the number of information bits in a packet of size F bits.

R is the transmission rate in bits/sec using strategy s_i.

$f^c(\gamma_j)$ is the efficiency function which increases with expected SINR of the receiving node and is given by

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$$f^{C}(\gamma_j)=(1-2(BER_{coded}))^{F} \quad (6)$$

Substituting eqns. (2) and (6) in eqn. (5), the utility of the game considering VMIMO along with MIDRS code is obtained. Each sensor node tries to maximize its own utility by adjusting its own power optimally as given by utility function. The utility function from a sensor node's viewpoint considers the interference it gets from other nodes; however, it ignores the fact that this node imposes on itself in terms of drainage of energy. Pricing is effective in regulating this externality, as it encourages the nodes to use resources more efficiently. The pricing accounts for the energy consumed/drained by the sensor nodes with usage of resources (transmission power). If the strategy of the i^{th} node is to transmit at signal power $s_i \in S$, the price acquired is a function of s_i, which is denoted by $A(s_i)$. Considering a linear cost function,

$$A(s_i)=k\times s_i \quad (7)$$

where k is a scaling factor.

Then the utility with pricing if a node is transmitting is given by

$$u_i(pricing) = u_i(s_i, s_{-i}) - A(s_i) \quad (8)$$

With the BER, the power efficiency is calculated and is given by

$$Power\ Efficiency = \frac{(1-BER)^F}{\frac{s_i}{min(M_T, M_R)}} \quad (9)$$

where

F is the packet size

s_i is the transmit power in mW

The network lifetime is the period of time from the network initialisation to the point when the first node runs out of energy and is given as

$$T_{net} = \min\{T_{co1}, T_{co1}, .., T_{non-co1}, T_{non-co1}, ..\} \quad (10)$$

The lifetime of the sensor node which takes part in MIMO communication is given by

$$T_{co} = \frac{E_0}{s} \quad (11)$$

where

E_0 is the residual energy of the node

s is the power consumption of the node

$$E_0 = E_i - E_t \quad (12)$$

where

E_i is the initial energy of the node

E_t is the energy consumption of the node in the previous round

For the remaining nodes which do not take part in data communication, the energy consumption is assumed to be negligible and its lifetime is given by

$$T_{non-co} = \infty \quad (13)$$

IV. RESULTS

The analysis of the proposed power control scheme with MIDRS code for the virtual MIMO wireless sensor network using game theoretic approach is carried out using MATLAB 7.0. The parameters considered for simulation work are tabulated in Table 1.

Table I. Simulation parameters

Simulation Parameters	Description
Network area	$100\times100m^2$
Transmit power $\{p_{min}:p_{max}\}$	1-100mW
Channel Bandwidth	1MHz
Data rate	20kbps
Path loss component	2
RS Code	(31,29,3)
Modulation technique	QPSK
Initial energy of the sensor nodes	4J
Frequency	2.5GHz
Noise spectral density	-171dBm/Hz
Number of transmit and receive antennas	2,3,4

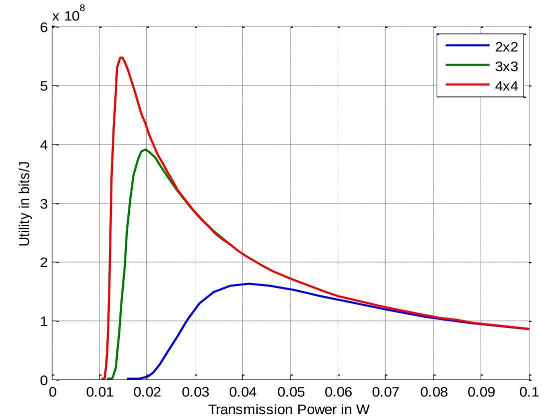

Fig.1. Utility of the game without pricing

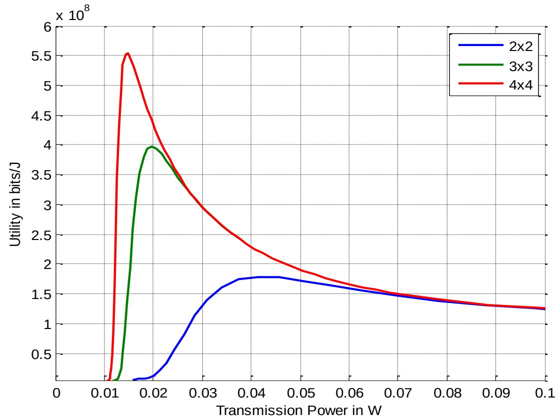

Fig.2. Utility of the game with pricing

The utility is observed as a function of transmit power for various diversity(2x2, 3x3, 4x4) and is shown in Fig.1. For 2×2 MIMO WSN, a maximum utility of 1.6×10^8 bits/joule is achieved for a transmission power of 40mW, whereas with 3×3 and 4×4 an utility of 3.8×10^8 bits/joule and 5.4×10^8 bits/joule is achieved for a transmission power of 19.5mW and 14.5mW respectively.

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4x4 MIMO scheme with MIDRS coding provides nearly 42% increase in utility for 26% reduction in power as compared to 3x3 MIMO scheme with MIDRS code and nearly 200% increase in utility for 63% reduction in power as compared to 2x2 MIMO scheme with MIDRS code.

Pricing helps the nodes to utilize resources more effectually. If a particular node in the network tends to increase its transmit power such that it creates interference to the other nodes, then the effect of pricing decreases the utility of that node by pricing factor K and increases the utility of the other nodes by pricing factor K. From fig.2 it is observed that the game with pricing provides an increase in utility for the same power achieved for the game without pricing. It is further inferred that, 4x4 MIMO scheme with MIDRS code and pricing provides a maximum utility of 5.55×10^{8} bits/joule at the transmission power of 14.5mW. An increase in utility by 3% is obtained by considering the pricing strategy.

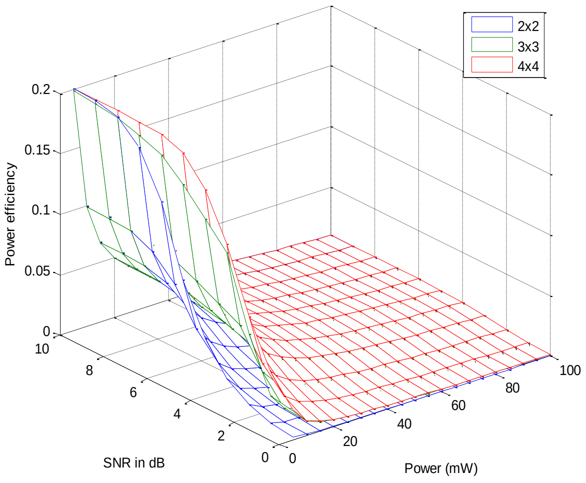

Fig.3. Power efficiency

Power efficiency considering 2×2, 3×3 and 4×4 MIMO with MIDRS code are shown in Fig.3. From this figure it is inferred that at high SNR increasing the transmitting power unnecessarily decreases the power efficiency below the maximum. Hence at high SNR, a node should transmit at low power to maximise its power efficiency. At low SNR the power efficiency is very low for all power levels and hence the node should not transmit under such worse channel conditions.

The energy consumption of 2x2, 3x3, 4x4 MIMO scheme with MIDRS code is shown in Fig.4. From this figure it is evident that as the distance increases the energy consumption of the node gradually increases. STBC coded 4x4 MIMO scheme with MIDRS code reduces the energy consumption by 20% and 32% compared 3x3 and 2x2 MIMO scheme with MIDRS code respectively for a distance of 100m. The decrease in energy consumption is due to the MIDRS code employed along with the increase in diversity order. Moreover, the maximum number of cooperative nodes used for simulation is restricted to four as further increase of it introduces hardware complexity and cost of the system.

Maximising the network lifetime is an important criterion in sensor network as the replacement of battery is not feasible. Fig. 5 shows the network lifetime with increase in distance. As the diversity order increases, the energy consumption decreases and number of rounds for which the nodes are alive increases. For a distance of 100m, it is inferred that incorporating 3x3 MIMO scheme with MIDRS coding increases the network lifetime by 36% compared to 2x2 MIMO scheme. 4x4 MIMO increases the network lifetime by 10% compared to 3x3 MIMO scheme.

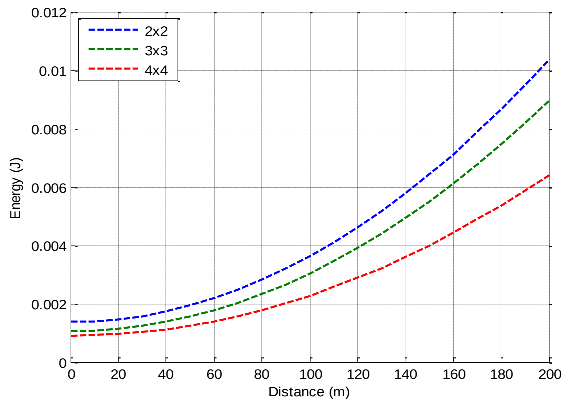

Fig.4. Energy consumption

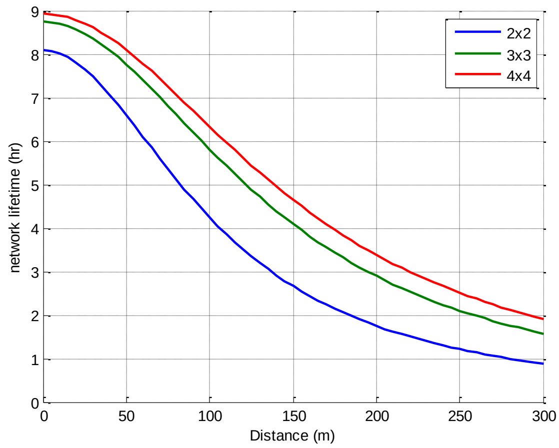

Fig.5. Network lifetime

V. CONCLUSION

The performance of the virtual MIMO scheme with MIDRS code is evaluated for various orders of diversity in terms of utility, power efficiency, energy and network lifetime. Simulation results prove that 4x4 MIMO scheme with MIDRS code provides nearly 42% increase in utility for 26% reduction in power as compared to 3x3 MIMO scheme with MIDRS coding. With the inclusion of MIDRS code in VMIMO WSN the energy consumed is reduced significantly and the network lifetime is enhanced. 4x4 MIMO on an average consumes 20% less energy consumption for packet transmission than 3x3 MIMO configuration. The network lifetime is enhanced by 10% for a 4x4 MIMO scheme compared to 3x3 MIMO scheme. This results from the reduction in BER and diversity gain of higher order MIMO configurations.

REFERENCES

1. L.Akyildiz, W.Su, Y.Sankarasubramanian, E.Cayirci, "A survey on sensor networks," IEEE Communications Magazine, vol.40, no.8, 2002, pp.102-114.
2. Shraddha Srivastava, Christian Spagnol, Emanuel Popovici, "Ananlysis of a set of error correcting schemes in multi-hop wireless sensor networks," Proceedings of IEEE PRIME 2009, Ireland. pp.1-4
3. S. Buchegger, and J. Le Boudec, "Performance Analysis of the CONFIDANT Protocol," Proceedings of Third ACM International Symposium on Mobile AdHoc Networking & Computing, 2002, pp.226-232.
4. L. Buttyan, and J.P. Hubaux, "Nuglets: A Virtual Currency to Stimulate Cooperation in Self organized Mobile Ad-Hoc Networks," Technical Report DSC/2001/001, Swiss Federal Institute Of Technology, January 2001.
5. W. Wang, M. Chatterjee, and K.Kwiat, "Enforcing Cooperation in Ad Hoc Networks with Unreliable Channel," Proceedings of Fifth IEEE International Conference on Mobile Ad-Hoc and Sensor Systems (MASS), 2008, pp.456-462.
6. V. Srinivasan, P. Nuggehalli, C.Chiasserini, and R.Rao, "Cooperation in Wireless Ad Hoc Networks," Proceedings of IEEE INFOCOM, April
7. 2003, pp. 808-817.
8. S.Cui, A.J.Goldsmith, A.Bahai, "Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks," IEEE Journal on Selected Areas in Communications, vol 22, no.6, 2004, pp. 1089-1098.
9. S. K.Jayaweera, "Energy analysis of MIMO techniques in wireless sensor networks," Proceedings of Annual Conference on Information Sciences and Systems, Princeton, NJ, 2004; pp. 1-6.
10. F. Parvaresh and A. Vardy, "Multivariate Interpolation Decoding Beyond the Guruswami Sudan Radius," 42nd Annual Allerton Conference on Communications, Control, and Computing, Illinois, September 2004.
11. R.Valli, A.Sharmila and P.Dananjayan "Utility based power control with pricing using MIDRS codes in Wireless Sensor Networks," Proceedings of IEEE International Symposium on Humanities, Science and Engineering Research, Kualalumpur, Malaysia, 5-7 June 2011.
12. D.Fudenberg and J.Tirole, Game Theory, MIT Press, Cambridge, MA, 1991
13. Shamik Sengupta, Mainak Chatterjee, and Kevin A. Kwiat, "A Game Theoretic Framework for Power Control in Wireless Sensor Networks," IEEE Transactions on Computers, vol 59, no.2, February 2010, pp.231-242.
14. W.Heinzelman, A.Chandrakasan, and H.Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," IEEE Transactions on Wireless Communication. vol.1, no.4, 2002, pp. 660-670.
15. Xiaohua Li, Mo Chen and Wenyu Liu, "Application of STBC encoded cooperative transmissions in wireless sensor networks," IEEE Signal Processing Letters, vol.12, no.2, February 2005, pp.134-137.
16. R.Valli, P.Dananjayan, "A Non-Cooperative Game Theoretical Approach for Power Control in Virtual MIMO Wireless Sensor Network," International Journal of UbiComp (IJU), vol.1 no.3, 2010, pp.44-55.

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