ORIGINAL ARTICLES

On the Design of Space-Time Trellis Codes for Cooperative Networks

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ABSTRACT

A cluster-based cooperative multiple-input-multiple-output (MIMO) scheme is proposed to reduce the adverse impacts caused by radio irregularity and fading on the energy consumption model developed. A hybrid automatic repeat-request (ARQ) code combining scheme employing different multidimensional space time trellis codes (MSTTCs) over a multiple-input, multiple-output (MIMO) channel is described and also hybrid code combining technique is proposed for a cluster based cooperative wireless networks. The retransmission codes are designed using sub-optimal partition chains of the MSTTC super-constellation using a relatively simple search. Theoretical performance analysis and simulation results are provided. In distributed wireless networks, where nodes actively participate in helping communication for other nodes, they are typically unaware of their neighborhood and hence have to “estimate” it before sending any useful data. In this paper, we formalize the concept of node neighborhood by introducing the notion of network channel, in which all nodes become part of a large channel. In this paper, the optimal parameters to minimize the overall energy consumption are found, such as the number of clusters and the number of cooperative nodes. Simulation results exhibit that the proposed scheme can effectively save energy and prolong the network lifetime based on their nodes.

Key words: Cluster, Automatic Repeat Request, SINR, TCM.

Introduction

Due to the limited energy and difficulty to recharge a large number of sensors, energy efficiency and maximizing network lifetime have been the most important design goals for wireless sensor networks (WSNs). However, channel fading, interference, and radio irregularity pose big challenges on the design of energy efficient communication and routing protocols in the multi-hop WSNs. In this paper, we derive the throughput for various diversity combining techniques with turbo coding. Based on the derivations we comment on their suitability for various applications. In addition we examine a hybrid-ARQ selection technique based on SINR. The paper is organized as follows: Section II explains the different hybrid ARQ schemes, Section III identifies system model Section IV discusses a hybrid ARQ based on SINR estimation and Section V presents a conclusion. Traditional automatic repeat request (ARQ) error control techniques (R. H. Deng Elect. Letters, vol. 27, pp. 866-868, May 1991) are based on error detecting codes and rely on multiple transmissions of the same codeword to improve the reliability of a communications link. Hybrid-ARQ error control combines forward error correction and error detection in an attempt to improve the throughput of ARQ-based techniques. Combines multiple copies of a codeword to produce a lower rate codeword with improved performance. When code combining is used in conjunction with error detection, re-transmissions provide the multiple copies of the codeword. Each new copy of the codeword is combined with previous copies to form codewords from successively lower rate codes. Though the role of channel coding as a fundamental construct is clear in the above cited analysis, the role of network protocols like routing and medium access remains unclear. In fact, it is not even clear if these protocols are fundamental constructs or not.

Clustering in CWN:

In Fig (1) & Fig (2) explain the structure of macro and micro cooperative network. For sorting the information and to infer the rules, find causes and effects, detect patterns, etc. clustering can be used (F.H.P. Fitzek November 2006.) Clustering is used for grouping nodes that are close to each other in the network, and reduces energy consumption which can be either useful or wasteful in mobile network illustrated by Q. Zhang, F.H.P. Fitzek (2007). If at least one node in the cluster receives the packet without error, the packet is successfully received. The status of error free packets is sent to the cluster heads by the nodes using a low bit
rate message and the cluster head chooses one of those nodes to forward the packet to the next cluster. The member nodes in the cooperative cluster transmit the received packets to the cluster head, if necessary.

The intra-cluster transmission power is much smaller than the power of the inter-cluster transmission because the distance between the cluster nodes is smaller than the distance between the transmitter and the receiver from different clusters. In the distributed cooperative paradigm, packets are relayed from one cluster of nodes to the next cluster of nodes, until they reach the destination but not from network node to other network nodes showed that Y. S. Jung et al (2005). Cluster head decides if cooperation is necessary.

Unlike the node to node cooperative cluster transmission, a packet is successfully received if at least one node in the cluster receives the packet without error. The nodes with the error free packet send their status to the cluster head using a low bit rate message.

![Fig. 1: MacroNetwork.](image1)

![Fig. 2: MicroNetwork.](image2)

2. Literature Review:

2.1 Forward Error Correction (FEC) Techniques:

Erasure codes are used in Forward Error Correction FEC techniques to reduce or remove the need for retransmissions in presence of communication errors. The key idea behind an erasure code is to encode a set of k source data packets into a set of n \( \geq k \) encoded data packets in such a way that any subset of k encoded packets allows the reconstruction of the original sources. Such a code is called an (n, k) erasure code. The layer-aware FEC (L-FEC) generates repair symbols so that protection of less important dependency layers can be used with protection of more important layers for combined error correction. The L-FEC approach is exemplary applied to rate-less LT and Raptor codes. Gains for more important layers can be achieved without increasing the total FEC code rate.

ARQ Techniques:

A novel Automatic Repeat request (ARQ) technique based on the Turbo coding principle. The technique uses the log-likelihood ratios generated by the decoder during the previous transmission as a priori information when decoding retransmissions indicated by S. Lin and P. S. Yu (1982). However, the advantages of the proposed technique are that it is simple, it does not increase the decoder complexity beyond that required for the normal decoding of the original rate Turbo code, and it does not impose storage requirements at the receiver. Traditional automatic repeat request (ARQ) error control techniques discussed by Q. Zhang, F.H.P. Fitzek et al (2006) are based on error detecting codes and rely on multiple transmissions of the same codeword to improve the reliability of a communications link. This selective hybrid ARQ scheme considers metric ratio combining (MRC), Chase combining and code combining. It also proposes an expression for the selection of
hybrid ARQ schemes based on a signal-to-interference-plus-noise-ratio (SINR), in the presence of co-channel interference.

In Selective-Repeat ARQ scheme, it is assumed that the sender continuously transmits packets whose error process is characterized by means of a two-state Discrete Time Markov Channel. At the receiver these packets are checked for errors and ACK/NACK messages are sent back to the sender accordingly. The feedback message is known at the transmitter channel slots after the packet transmission started. The only drawback of the exact analysis is that its complexity.

A hybrid automatic repeat-request (ARQ) code technique has been proposed in Kingsley Oteng-Amoako et al., (2003). It combines the scheme employing different multidimensional space time trellis codes (MSTTCs) over a multiple-input, multiple output (MIMO) channel. The retransmission codes are designed using sub-optimal partition chains of the MSTTC super-constellation using a relatively simple search. The MSTTCs designed using the sub-optimal partition chains are, by themselves, not optimal codes.

Fig. 3: Co-Operative Network Receiver model.

Problem Identification and Solution:

In the cluster-based code combining method [6], the main drawback is the energy consumption of cluster nodes and the cluster head. This is because, the nodes in each cluster consumes more energy by using the forward error correction followed by the automatic repeat request. This will decrease the energy level of the cluster head before they reach their destination, resulting in data loss at the receiver. Certain overheads are produced by the additional FEC packets which depend upon the size of the FEC groups. Smaller the FEC group, larger the overhead and vice-versa. Larger delays are due to larger FEC groups. High bit rate leads to decrease in delay which consumes extra bandwidth for retransmission of packets Chadi Barakat et al., (2003). But these FEC systems are not highly reliable, since the probability of decoding error is usually greater than the probability of an undetected error. A large number of patterns can be corrected in order to achieve high system reliability. Constant throughput even with poor channel conditions can be achieved by combining the benefits of high reliability ARQ and advantages of FEC As the channel rate increases, the throughput of the system decreases. So in a FEC system, both high system reliability and high throughput cannot be achieved by Chadi Barakat et al., (2003). Due to the underlying packet structure, the amount of incremental redundancy may be high when it is applied to packet-based transmission systems, which is a drawback in hybrid ARQ techniques. And so efficiency is lost The unwanted complicated ARQ mechanism will cost in terms of processing power, ease of implementation and possibly also in interoperability. This may decrease the appreciation and the value of the whole MAC standard Norfishah Ab. Wahab et al., (2010) Not much bandwidth is consumed in ARQ. In this paper, we wish to develop an energy efficient clustering technique for cooperative wireless networks. In this technique, the cluster heads are selected based on their residual energy. (i.e). The node with more residual energy is selected as a cluster head. Initially the ARQ technique is used as the code combining technique when the energy level of the nodes in cluster is more. When the energy level of the cluster nodes reduces beyond a threshold, it chooses FEC as the code combining technique.

Trellis Coded Modulation(TCM):

TCM modulation that combines coding and modulation to achieve a great coding gain without scarificing bandwidth efficiency.

\[
\text{Modulation rate} = \frac{K(K+P)}{K(K+P)} \quad (1)
\]

K - Information bits
(K+P) - Coded bits.
The convolution encoder can map the coded bits on to signal points \(X_k\) through a technique called mapping by set partitioning. TCM uses multilevel/phase signalling set that signals constellations with multiple amplitudes and multiple phases. The signalling sets combine with state oriented trellis coding scheme discussed by R. H. Deng et al. (1991). The TCM achieves coding gain without any bandwidth but the expense of decoder complexity. In Fig (4) and Fig (5) shows the the Uncoded PAM is coded to a TCM by taking \(K=2\) and \(P=1\) which is the rate of \(K(K+P)=2/3\). The TCM is the same as a 2/3 coded 8 ary PAM with the same power with retransmission.

**Fig. 4:** Uncoded 4-ary PAM.

**Fig. 5:** TCM of a 4-ary.

**Fig. 6:** Uncoded 4-ary.

**Fig. 7:** TCM of a 4-ary.

\((k=2; p=0; \text{Transmission rate } R_1)\) \((k=2; p=1; \text{Transmission rate } R_2)\)
Table 1: Simulation parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Nodes</td>
<td>30, 60, 90 and 120</td>
</tr>
<tr>
<td>Area Size</td>
<td>1000 X 1000</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>50 sec</td>
</tr>
<tr>
<td>Traffic Source</td>
<td>CBR</td>
</tr>
<tr>
<td>Packet Size</td>
<td>512</td>
</tr>
<tr>
<td>Rate</td>
<td>1000 Kb</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>0.360 w</td>
</tr>
<tr>
<td>Receiving Power</td>
<td>0.395 w</td>
</tr>
<tr>
<td>Idle Power</td>
<td>0.335 w</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>AODV</td>
</tr>
</tbody>
</table>

Fig (6) & 7 shows an uncoded 16 QAM to a TCM by taking $K = 4$ and $P = 1$, which is a rate of $\frac{K}{K+p} = \frac{4}{5}$. This new TCM is the same as a 4/5 coded 32-ary QAM with the same power $P_t3$ and the same rate $R_3$ as the uncoded 16-ary QAM.

**Simulation Results:**

In this section, we present the simulation result for a HARQ using TCM. It is assumed that each network consists of 120 nodes. The set of MSTTCs used for generalized code combining found by the simple search algorithm improved the FER performance (relative to conventional code combining) by about 0.5 dB after 2 transmission, and by about 0.8 dB after the 3rd transmission I. Martin et al., (2000). As a consequence, generalized code combining requires fewer transmissions than conventional code combining J. Yu, Y. Li, H. Murata, et al., (2000). This results in higher throughput as illustrated in Figure 9. As expected, the improvement in packet received for a given amount of energy. Fig: 10 shows. The number of nodes consumes power per unit time.

**Fig. 8:** Total number of packets received at the sink.

**Fig. 9:** Total number of packets received at the sink per a given amount of energy.
Fig. 10: Nodes alive per given amount of energy.

Fig. 11: Nodes alive different SNR.

It is assumed routes for a network with 100 nodes, estimation phase is 100 packet transmissions, and data transmission period constitutes of 1000 packet transmissions.

Conclusion:

In this paper, the performance of hybrid ARQ scheme employing turbo codes in employing different multidimensional space time trellis codes (MSTTCs) over a multiple-input, multipleoutput (MIMO) channel is described. Figure 8. and Figure 9. present simulation results for energy consumption and number of packets received and for various nodes. We also proposed a selective hybrid diversity combining scheme based on SINR. Figure 8. and Figure 9. shows number of nodes alive based on the energy and SNR. The SINR criterion is reducible to SNR in the single user channels. The selection criteria results in a bandwidth efficient scheme that also exhibits high Throughput. In the clustering algorithm, we select cluster heads based on the connectivity and the residual energy of each node so that energy of the cluster head doesn’t get drained before reaching the destination. In our code combining technique, we have designed a clustering architecture which consists of source cluster, destination cluster and relay clusters. Each source node’s message is distributed to all the member nodes in the source cluster and then encoded using LDPC. The cluster head of the first relay cluster receives the encoded data from the source cluster and it decodes the data. If the data sent by the source cluster is not correctly decoded, the cluster head sends a NACK using the selective repeat ARQ. Otherwise, the cluster head divides the data among its cluster members and again encode the data and sends to the cluster head again. The cluster head sends the encoded data to the cluster head of the next relay cluster. This process continues until the data reaches the destination cluster which again decodes and sends it to the intended destination node. Since decoding is done at each cluster error recovery time is minimized and reliability is increased. Using this technique, we can obtain immediate error recovery with less energy consumption.
References


