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# Channel Resource Assignment Cross Layer MIMO Cooperative Scheduling Scheme for Hybrid Sensor Networks

Yingji Zhong, Kyung Sup Kwak, and Dongfeng Yuan

UWB Wireless Communication Research Center, Inha University, Incheon, 402-751, Korea

School of Information Science and Engineering, Shandong University, Ji'nan, Shandong 250100, China

e-mail: zhongyingji32@sdu.edu.cn

***Abstract*—The multi-scenario topology of the hybrid sensor networks is studied and a novel MIMO Channel Resource Assignment Cross Layer Cooperative Scheduling Scheme (CRA-CCSS) is proposed in this paper. The comparison and the predominance of the proposed scheme are demonstrated. With the help of the simulations, the relative energy consumption and the end-to-end blocking probability are all improved. So the addressing ratio of success in the condition of the unchanged parameters and external information can be increased and the network can tolerate more hops to support reliable transportation by the proposed scheme. What is more, the scheme can make the network more stable and support more hops. Therefore, the proposed scheme can enhance the average rate performance of the hybrid sensor networks and make the outage probability stable.**

*Keywords:* Cross Layer, MIMO, Cooperative Scheduling, Hybrid Sensor Networks

## I. INTRODUCTION

THE hybrid sensor networks[1] give the novel infrastructure which combines cellular networks with self-organize mechanism. We believe that the topology space analysis in the special scenario should be beneficial for the proposal of the novel scheme to effectively utilize location marking information and then address the performance issues. The cooperative scheduling has attracted much attention in these days for realizing frequency sharing system at the frequency band assigned to the primary system. In the cooperative process, the secondary cooperative terminals transmit the signals on the frequency band assigned to the primary system by sensing the radio frequency band in order to avoid the interference toward the primary systems. However, it is difficult to recognize the status of the frequency band when the primary terminals only receive the signals. Therefore, the proposal of the MIMO cooperative scheduling in order to realize a wide area secondary communication system by using multi-hop networks is necessary. Although the large transmission power on single-hop networks can support the large communication area, the interference toward the primary system also becomes large if the primary system exists between the primary transmitter and the receiver. In the sensor cooperation, the power of each node is suppressed to minimize the interference toward the primary system and the area of communication can expand by using the multi-hop networks[2]. However, the scheduling framework is complicated because the location and the active time of the primary system are not fixed. To our assumption, the hybrid sensor networks has the potential to enable a large class of applications ranging from assisting elderly in public spaces to border protection that benefit from the use of numerous sensor nodes that deliver packets. In multi-hop wireless networks, there is a strict interdependence cross layer coupling of functionalities among functions handled at all layers of the communication stack. Multiple paths may exist between a given source-sink pair, and the order of packet delivery is strongly influenced by the characteristics of the route chosen.

In order to improve the robustness of the sensor cooperation without complicated scheduling framework, we propose a novel cross layer MIMO cooperative scheduling scheme for the hybrid sensor networks in this paper. Addressing the existing questions and designing a viable end-to-end solution may be the first attempt. We also identify key design parameters and present a methodology to optimize cross layer efficiency, data quality and coverage area. To the best of our knowledge, such a study has not been thoroughly conducted in [3] and [4]. To describe the system implementation of the proposed scheme, we give a novel cross layer communication architecture. The proposed architecture gives modified wireless link abstractions and suggests tradeoff in complexity at the physical and higher layers. To this end, the scheme we proposed can support packet-based delay guarantees that must be delivered with a given probability. In this case, MIMO cooperative communication considerably improves the network connectivity. The proposed scheme gives a measure of the probability that a packet reaches its destination within required delay bounds. It is based on a cross layer approach between the network and the MAC layers in which a judicious choice is made over reliability and timeliness of packet arrival. It is argued that the differentiation in reliability is an effective way of channeling resources from flows with relaxed requirements to flows with tighter requirements.

The rest of the paper is organized as follows. In Section II, we give the evaluation architecture. In Section III, we propose the cross layer architecture and the cross layer MIMO cooperative scheduling scheme. In Section IV, we evaluate the performance of the proposed scheme and analyze the improvement of the cooperative scheduling guarantee via simulation. Finally we give the conclusion in Section V.

## II. EVALUATION ARCHITECTURE

In randomized cooperation, each node projects the rows of the state matrix can generate a randomized state $\tilde{x}_r = Xr_r = G_{M\times N}(s)r_r$ .The received vector is the mixture of these randomized states convolved with their respective channel impulse response

$$y_i = \sum_{n=1}^{N} M_{i,n}\, x_n + \delta_i \qquad (1)$$

where the $M_{i,n}, n = 1,\dots,N$ are the equivalent convolution matrix and the received vector is equivalent to that of $N$ cooperative states. The diversity that can be obtained through this scheme depends on the statistics of the resulting equivalent states and on the particular selection of the state $G_{M\times N}(s)$ just as it does for the deterministic assignment. For simplicity and to gain intuition, we consider the transmission model where the channel between the source node S and the destination node D are orthogonal and $i$=1,2,3,4. A message that contains a request for cooperation is stored in the relay buffer, whose transmission is synchronized by the preamble sequence received in the message containing the request. The state parameters in network layer need to be informed about the state of the relay buffer. In general, the half-duplex constraint of the transmission model mandates that the destination node be inactive when the source node is busy, but the upper layer can also prevent cooperative transmission for it. As shown in Fig.1.

As in the case with only amplify-and-forward, the resultant composite signal at the relay is

$$\tilde{y} = \begin{bmatrix} M_1 \\ \beta M_2 \end{bmatrix} x + \begin{bmatrix} m_1 \\ m_2 \end{bmatrix} \qquad (2)$$

where $\beta = (\sqrt{G\frac{P_r/2}{M_2\sum_x M_2^T+1}})/(1+\sqrt{G\frac{P_r/2}{M_2\sum_x M_2^T+1}})$ .For fixed $\beta$, $P_t$ and $P_r$, the sum rate achievable from the cooperative transmitter to the receiver is equal to the sum capacity of the dual multiple-access channel. The sum capacity must be characterized in terms of maximization as

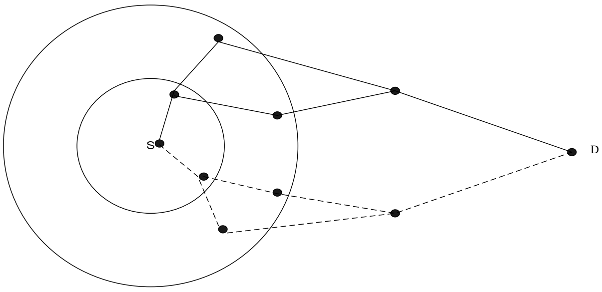

Fig.1. Transmission model

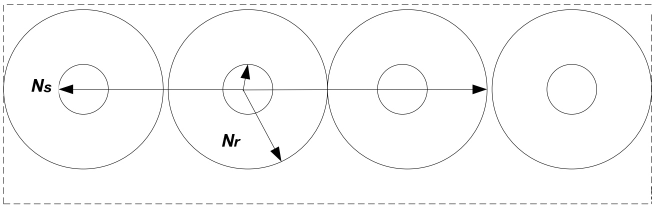

Fig.2. Dual ring topology multi-scenario architecture

$$R^{coop} = \max_{T_r(Q_1+Q_2)\le P} \log\left| I + \tilde{M}_1^T N_s \tilde{M}_1 + \tilde{M}_2^T N_r \tilde{M}_2 \right| \qquad (3)$$

where the maximization is over covariance matrices $Q_1$ and $Q_2$, with $\tilde{M}_1 \overset{\Delta}{=} \begin{bmatrix} M_1 \\ \beta M_2 \end{bmatrix}$ ,and $\tilde{M}_2 \overset{\Delta}{=} \begin{bmatrix} \beta M_1 \\ M_2 \end{bmatrix}$. For fixed $P_t$ and $P_r$, the achievable minimum rate is $min(2R_t,R^{coop})$. As for the multi-scenario shown in Fig.2, the relays are used for exchanging control messages and assigning the dedicated channel. In high bandwidth applications, the use of a separate channel for channel arbitration alone does not allow best utilization of the network resources. It is necessary to directly maximize the achievable rates over all choices of $P_r$, where the same channel is used for both data and channel arbitration. The scaling term $\beta$ can be made close to one. Thus the composite channels capacity is equal to the point-to-point MIMO capacity of the original channel [5]. Such model undoubtedly improve bandwidth efficiency and introduce the problem of distinct channel assignment and need to account for the delay to switch to a different channel as its cumulative nature at each hop affects flows.

The above analysis demonstrates that only considering channel assignment and routing are not good enough in hybrid sensor networks. To fully reduce the co-channel interference and consequently achieve higher gains of network performance, the topology attributes and cooperative scheduling should be jointly considered to exploit not only channel diversity but also spatial reusability.

## III. CROSS LAYER ARCHITECTURE AND CROSS LAYER COOPERATIVE SCHEDULING SCHEME

### A. Cross Layer Communication Architecture

Appropriately weighted and seamlessly integrated with a suitable channel access policy allows adjustments to be made to

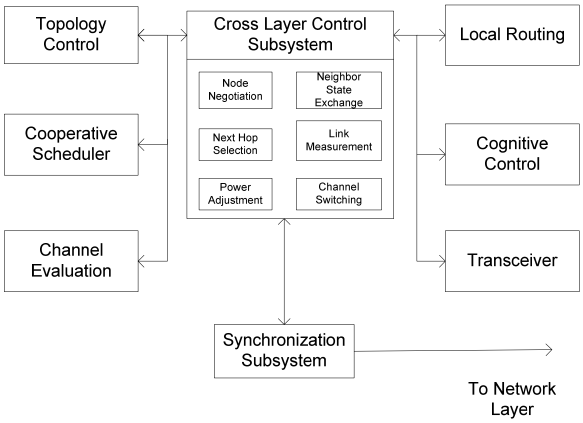

Fig.3. Cross layer communication architecture

the energy-latency-fidelity trade-off space. Existing solutions often do not provide adequate support for broadband applications since the resource management, adaptation, and protection strategies available in the lower layers of the stack are optimized without explicitly considering the specific characteristics of the hybrid sensor networks.

Similarly, data compression and streaming algorithms do not consider the mechanisms provided by the lower layers for error protection and resource allocation. Depending upon our proposed cross layer communication architecture, it is possible to adapt our scheme for greater energy savings, albeit at the cost of a small, bounded increase in worst-case packet latency. We assume that the channel error is fully predictable at any time and its practical implementation shows marked deviations from the idealized case in terms of the complexity. Bounds on various performance measures, such as delay and queue length, at each element of the network can be derived and thus the flow can be specified. Fig.3 outlines the proposed architecture.

The cross layer control subsystem consists of six modules: link measurement, neighbor state exchange, node negotiation, next hop selection, power adjustment and channel switching. Among them, link measurement module is utilized to collect the link status information. The estimation of link packet loss ratio is based on the approach introduced in [6]. The next hops are selected by the cross layer control subsystem by applying an admission control procedure that verifies that each node on the path be able to provide the required service level. The channel switching allowed delay calculated at each step based on the relative advance of each hop towards the destination. As to the traffic load information, time sliding window method is employed to measure the traffic rate on a link. In the neighbor state exchange module, each node broadcast HELLO message several times with different transmission power levels sequentially at the network setup phase. The specific power level of the source and previously inferred neighbor information from the received HELLO message are piggybacked in the HELLO message. Through the information exchange, node can get the basic neighbor state under different power levels at the beginning. After that, node periodically broadcasts the traffic rate, packet loss ratio for each active link together with the channel and power information to its neighbors. The information of its corresponding neighbor nodes is also piggybacked in this packet. In this way, node can obtain the traffic and link status within multi-hop range. The node negotiation module is implemented to coordinate nodes and complete the adjustment. The physical, MAC, and network layers together impact the contention for network resources. The physical layer has direct impact on the multiple accesses of nodes in wireless channels by affecting the interference at the receivers. The MAC layer determines the bandwidth allocated to each transmitter, which naturally affects the performance of the physical layer in terms of successfully detecting the desired signals. On the other hand, as a result of transmission schedules, high packet delays or low bandwidth can occur, forcing the routing layer to change its route decisions. Different routing decisions alter the set of links to be scheduled, and thereby influence the performance of the MAC layer. Furthermore, congestion control and power control are also inherently as the capacity available on each link depends on the transmission power. Moreover, specifically to broadband transmissions, the application layer does not require full insulation from lower layers, but needs instead to perform source coding based on information from the lower layers to maximize the network performance.

The physical layer sub-problem addresses the transmission interference among nearby nodes and provides to the upper layers a convex set of capacity graphs supported by a finite set or basis of elementary capacity graphs in the cognitive control module. This is equivalent to saying that finding the ensemble of flows in all the links which attain the maximum total flow is *NP*-complete. If the nodes result in an action profile where each user's action is a best response to the others in the cooperative scheduler module, the Nash equilibrium is reached[7]. In other words, the Nash equilibrium is the action profile $(p_s^*, n^*, p_r^*, m^*)$ where no user has an incentive to deviate by choosing another action given that the other user's action is fixed. Formally, the Nash equilibrium can be acquired by the following action profiles for each node.

$$\begin{aligned} &(p_r^*, m^*) = \arg\max U_r^{mh}(N_r, m) \text{ s.t. } 0 \le N_r \le p^{\max}, \\ &m \in (0,1),\ mf(\gamma_{sa}) \le n^* f(\gamma_{sr}^*) \\ &(p_s^*, n^*) = \arg\max U_s^{mh}(N_s, n) \text{ s.t. } 0 \le N_s \le p^{\max}, \\ &n \in (0,1),\ nf(\gamma_{sr}) \le m^* f(\gamma_{ra}^*) \end{aligned} \tag{4}$$

For multi-hop transmission, the equilibrium action profile must satisfy the opposing throughput constraints of the maximization problems. This opposing throughput constraint is $l^* f(\gamma_{sr}^*) = k^* f(\gamma_{ra}^*)$. Clearly, the non-forwarding action profile $(p_s^*, 0, p_r^*, 0)$ in (4) satisfies the above constraint and always exists in the game. Generally speaking, both the transmit diversity and spatial reusability affect the network performance in the hybrid sensor networks.

### *B. Cross Layer Cooperative Scheduling Scheme*

The primary concern in our scheme is accomplished at the cost of latency and by allowing throughput degradation. A sophisticated duty cycle calculation based on permissible end-to-end delay needs to be implemented and coordinating overlapping listen period with neighbors based on this calculation is a difficult research challenge. When the end-to-end traffic can be split in the multi-dual ring scenario, the number of the routes between source and destination should be two or more. That is to say, the flow going through the route is no longer an integer and the traffic demands can split [8,9].

The novel Channel Resource Assignment Cross Layer Cooperative Scheduling Scheme (CRA-CCSS) is shown below.

```
 Init( )
{
   maximize $U_s(p_s, n)$ without constraints;
   maximize $U_r(p_r, m)$ ;
   analyze the contention of links on channel $c$ in two hop range;
      if $i$ is bound to nodes of neighboring cluster then
        assign $i$, the channel assignment from its neighbor assignment;
      else
          set $y_{ij}^{td} = y_{ji}^{td}$ and $i \neq 0$ iteratively update $q^{(\tau_i)}$
          as $q_l^{(\tau_i+1)} = \frac{\mu_l}{t_l^{(s)}} - \frac{1}{M_{ll}}(M_{lj} q_j^{(\tau_i)} + \sigma_l^2)$ ;
   project $q_l^{(\tau_i+1)}$ into power constraint interval $[0, q_{l,\max}]$ ;
 calculate the resource assignment for channel $c$;
     end if
  calculate $R^{coop}$ on channel $c$ and corresponding priority for each group;
   repeat until $q^{(\tau_i)}$ converges. Set $q^{(s+1)} = q^{(\tau_i)}$ ;
      if no channel overloaded
        return;
      end if
      if feasible
          select adjustment candidate with $R^{coop}$ and begin negotiation;
      end if
      if $(p_s^*, n^*, p_r^*, m^*)$ does not change
          Rate $s_n$
     end if
   analyze the contention of links on channel $c$ in two hop range;
   if $i$ is bound to nodes of neighboring cluster
      assign $i$, the channel assignment for the next assignment;
   end if
end
}
```

In our scheme, the non-forwarding action is always in Nash equilibrium. The topology construction is performed during the network initialization phase when no user traffic is present in the network. To fully reduce the co-channel interference and achieve higher gains of network performance, the topology attributes and power constraints should be jointly considered to exploit not only channel diversity but also spatial reusability. Firstly, we sort all the node pairs in ascending order according to their minimum distance. Secondly, $R^{coop}$ evaluation runs on every node in the network to check whether the flow can be all routed or not. Coordinating the sleep-awake cycles between neighbors is generally accomplished though MIMO scheduling exchanges. In case of dynamic duty cycles based on perceived values of instantaneous or time averaged end-to-end latency, the overhead of passing frequent schedules also needs investigation in light of the ongoing high data rate message. The operation should be terminated when the transmission power reaches to maximum. In this scheme, the topology and power consumption of each node can be optimized due to the minimum link occupation. The power update is the best response of link player given the tax rate and assessment of others' action. As for the tax rates converge, it can be induced to a stable Nash equilibrium. Such equilibrium strikes a balance between minimizing interference and maximizing rate.

## IV. SIMULATIONS AND DISCUSSION

The terrain model we used is a 24*km*×6*km* rectangular area with 4 dual rings in the multi-scenario. In each dual ring, the nodes are pseudo-randomly moving along the cluster cells under *NS*-2. All the links between nodes are bi-directional. Each cell has a base station with omni-directional antenna at the center point and its radius is 3*km*. Each node can support 256 available data channels. As for handoff mechanism, hard handoff was used in the evaluation model and connectivity is considered under Poisson Boolean Model in this kind of sparse network. We use 1024 TCP flows in the multi-scenario and the simulation time for each point is 3600s.

We assume that the power consumption is based on the distance from the transmitting nodes to the destinations. Employing the proposed scheme, the relative energy consumption and the end-to-end blocking probability are examined in different number of the nodes. As shown in Fig.4 and Fig.5 respectively. As expected, the use of the proposed scheme can optimize the available channel capacity and the relative performance.

Fig.4 gives the relative energy consumption with varying number of the nodes. As the relative gain increases, the achievable rates increase accordantly. The system with cooperative scheduling scheme performs better than the one without CRA-CCSS, which only outperforms strategy game. For large number, the ratio approximates 3, hence the gain in total energy consumption for the reliability balancing strategy is 27.5%. More important and more significant is the gain in network lifetime, which is determined by the lifetime of the current node. Notice that the two curves are independent of the channel states because they assume perfect condition. The proposed scheme is virtually identical to the MIMO cooperative scheduling until the point where the power gain comes very close to the real utility. Thus, it seems that is not necessary to do cooperation in the proposed scheme especially when the gain is interrupted by the addressing ratio and the permitted hops.

Fig.5 gives the end-to-end blocking probability with varying number of the nodes. Observe that when the node number is less than 5000, the probability of the end-to-end blocking is quite large because the throughput and the congestion is actually in idle state. This is reasonable because no multi-user diversity gain can be achieved in case there is only one user has longer scheduling time than that of MAC. When the number of the nodes increases, the throughput gain benefited from opportunistic scheduling starts to show. When the number of flows increases to 5000 or above, the probability of the end-to-end blocking exceeds 0.07% and the gain maintains relatively stable. The minimal optimization is 10.35% when the number of flows reaches to 12000. What is more, the addressing ratio of success in the condition of the unchanged parameters and external information can also be increased. The reason is that the

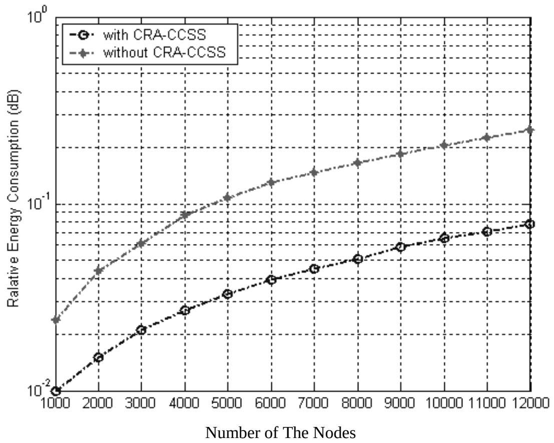

Fig.4. Relative energy consumption with varying number of the nodes

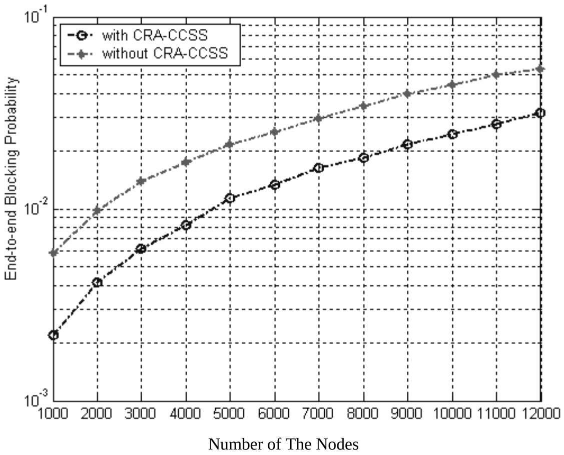

Fig.5. End-to-end blocking probability with varying number of the nodes

probability of all candidate receivers is not satisfied to receive a packet at any given time is very low. When the number of flows goes up, almost each time access point sends an RTS and receives CTS to continue data delivery. We can also evaluate the impact of varying the number of flows in the network. If more flows are setup between randomly chosen node pairs, the traffic load on each flow will be high and the end-to-end probability for a packet generated at the node will increase monotonically. The energy consumption is more balanced, and the end-to-end probability is constant. It is apparent that the system with CRA-CCSS offers significantly better performance than the ones without CRA-CCSS, averagely two times of the improvement is acquired.

## V. CONCLUSION

In this paper, a novel MIMO cooperative scheduling scheme with the given scenario in cross layer aspects was proposed. The comparison and the predominance of the proposed scheme are demonstrated by the new cross layer architecture and the simulation results analysis. The relative energy consumption and the end-to-end blocking probability are improved with the help of the simulations. The addressing ratio of success in the condition of the unchanged parameters and external information can be increased and the network can tolerate more hops to support reliable transportation by our scheme. What is more, the scheme can make the network more stable and support more hops. To sum up, the proposed scheme can enhance the average rate performance of the hybrid sensor networks and make the outage probability stable.

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