Spectrum-Aware Cluster Based Multimedia Routing (SCMR) For Cognitive Networks

Mr. Raghavendra L R[1], Mr. Anandaraju M B[2], Amulya M K[3], Chanchala M[4]

[1]Asst. Professor, Dept. of ECE, BGS Institute of Technology, Karnataka, India
[2]HOD, Dept. of ECE, BGS Institute of Technology, Karnataka, India
[3]Student, Dept. of ECE, BGS Institute of Technology, Karnataka, India
[4]Student, Dept. of ECE, BGS Institute of Technology, Karnataka, India

---

Abstract - *Multimedia applications have characteristics like delay sensitivity and high bandwidth which stipulate the traffic sources. It is difficult to support such applications for CRSN with energy and spectrum constraints. This paper proposes a spectrum-aware cluster based multimedia routing (SCMR) protocol for CRSNs that jointly overcomes the formidable limitations of energy and spectrums. By limiting the participating nodes in route establishment, clustering is achieved to support the Quality of Service (QOS) and energy efficient routing. In SCMR protocol, the distortion that occurs due to packet losses and latency in multimedia quality can be minimised when the number of cluster is optimally determined. The CH selection is based on energy and relative spectrum aware such that non-licensed spectrum bands are clustered and scheduled to provide continuous transmission opportunity. The data routing employs clustering with hybrid medium access by combining CSMA and TDMA. In CRSN, a cross layer design of routing, i.e., of MAC and physical layer provides efficient, multimedia routing prevailing over the energy and spectrum issues.*

Key Words*: *Spectrum-aware cluster based multimedia routing, WMSN - Wireless multimedia sensor network, cross-layer routing.

1. INTRODUCTION

CRNS observe the radio environment for a suitable band, a frequency-agile radio that can be tuned to a wide range of frequency bands, employ an intelligent agent for decision-making, and operate on an intelligently selected band. In this model spectrum utilization and regulation issues for exclusive use by the licensed or primary users (PUs) brings a revolutionary change by introducing a new type of unlicensed or secondary users (SUs) who can share the spectrum efficiently without interfering with the primary users. This model has also been utilized by the WSN to satisfy the potential benefits of CRs, thus forming CRSNs. In many different application scenarios, for instance, intelligent transportation systems, smart grids, industrial monitoring, surveillance, etc. CRSNs can be utilized. Dynamic spectrum access plays an important key role in reducing the noisy spectrum bands and eases the re-configuration of spectrum usage. In public transport vehicles, such as trains wireless multimedia sensors have been realized for monitoring and for intelligent transportation service. In vehicular networks the spectrum utilization issues for multimedia delivery have not been addressed adequately. In supporting demanding applications over CRSNs the limit of established infrastructure, constrained spectrum access privileges, and network dynamics, along with the unpredictable band opportunity and the nature of the wireless medium, offer an unprecedented set of challenges. There are many key issues, which are not dealt with in its counterpart wireless multimedia sensor network (WMSN) supporting multimedia applications of traditional WMSNs.

The multimedia routing protocol for CRSNs should exhibit the following properties.

Rate adaptation with opportunistic bandwidth: In conjunction with strict delay constraints the modern variable-rate encoder demands high and variable bandwidth. By adapting source rate according to the time-varying available capacity of CRs, this feature of multimedia streams should be best exploited in CRSNs.

Delay and jitter control: The varying capacity of wireless links deteriorates the performance of a routing protocol in achieving end-to-end delay bound in CRSNs. By setting a suitable play-out deadline the strict delay constraint is usually compensated for to take into account the underlying network bottlenecks. By setting appropriate deadlines in conjunction with play-out time, the multimedia routing protocol should notice the significant variation in delay and jitter to ensure the persistent QoS for multimedia applications.

Resource constraint: CRSNs face the challenges of resource limitations inherited from the traditional WSNs, which include mainly power, processing, and memory in addition to the unpredictable time-varying capacity of channels and complexity of CR itself. Therefore, the potential routing protocol should support the efficient resource utilization of sensor nodes. The mainstream CR research has focused on developing effective spectrum sensing and access techniques for the transmission of the unconstrained type of data on infrastructure based CRNs, the mainstream CR research has focused on developing effective spectrum sensing and access techniques and to some extent, for multi-hop CR ad hoc networks. Very little effort is made in the literature to support multimedia over multi-hop CRNs. Generally, centralized approaches are analyzed to provide optimal performance for CR communications. However, recent developments in this field has motivated the investigation of distributed algorithms to provide near optimal efficiency for infrastructure less wireless networks, particularly resource constrained WSNs. To this end, distributed clustering can efficiently deal with the resource limitations and scalability for densely deployed sensor networks.

This paper exploits the clustering algorithm to manage dynamic spectrum access and QoS routing for multimedia CRSNs. A spectrum-aware clustering protocol for multimedia routing (SCMR) is proposed in which channels are clustered using the spectrum sensing results obtained from each node and the past usage experience. In a clustering round, this is based on the phenomenon of scheduling available spectrum over Q slots. Similarly, routing is based on node clustering, in which a CH is elected that has higher residual energy and spectrum rank relative to its neighbours. Routing is integrated with a hybrid time division multiple-access (TDMA) and carrier-sense multiple access (CSMA) medium access protocol to relay intra-cluster and inter-cluster packets, respectively. In particular, the contributions of SCMR are threefold (First, for smooth operations of multimedia delivery SCMR isolates the time and frequency variability of the spectrum. Second, it preserves the QoS of each source with graceful degradation. Third, without compromising the multimedia quality SCMR achieves energy efficiency).

This paper proposes a novel spectrum aware clustering based multimedia routing (SCMR) protocol for CRSN to efficiently tackle the issues of energy consumption and dynamic spectrum access. In SCMR, by sharing the spectrum sensing results and residual energy among the nodes, channels are clustered along with the nodes. A high rank node is elected as a cluster-head that controls the spectrum access and data routing. Routing is integrated with a hybrid time division multiple access (TDMA) to relay intra-cluster and carrier sensing multiple access (CSMA) inter-cluster packets. To minimize the delay by exploiting spectrum diversity, such hybrid approach allows to simultaneously performing intra-cluster transmission and inter-cluster routing. Hence, route establishment and maintenance is only performed by cluster-heads to minimize the routing overhead.

2. RELATED WORK

The possibility of scalable video inn emerging CRN is investigated and also proposes cross-layer optimization approach in multicast video in [1]. The multi-media distortion of application layer Quality of Service (QoS) is reduced by secondary user, which may impede the success of CR technologies. This paper approaches an integrated design to jointly optimize multi-media intra refreshing rate in [2]. An application-layer parameter, together with access strategy and spectrum sensing for multi-media transmission in CR system with time varying wireless channels. A novel priority virtual queue interface that determines the required information exchanges and evaluates the expected delays experienced by various priority traffics is investigated in [3]. The impact of spectrum sensing frequency and packet loading scheme on multi-media transmission over CRN in [4] becomes important topic due to the CR's capacity of using unoccupied spectrum for data transmission and also means how frequently a CR user detects free spectrum. In [5], the auction-based scheme approaches for multi-media streaming in CR's to utilize the spectrum efficiently for data communications and little effort has been made in content-aware multi-media applications over CRNs. Multi-media communication cannot occur with the desired Quality of Service (QoS) until a contiguous frequency band in the spectrum with width at least equal to required bandwidth is obtained. To overcome this issue, a novel technique bases on Sample Division Multiplexing (SDM) is proposed in [6]. Depending on the type of signal and Quality of Service (QoS) requirements, such different type of multi-media signals needs different bandwidths for communication.

CRSNs have been recently realized and hardly a notable research is carried out in these emerging networks. Routing protocols have been extremely explored for WSNs, they cannot be exploited for CRSN due to their unawareness of dynamic spectrum access [7]. Routing protocols for cognitive radio ad hoc networks [8], [9] have also been explored but they do not address the energy constraint. A cluster-based QoS routing for multimedia delivery is proposed in [10] that consider multi-channels in WSNs with multiple interfaces, since the presence of PUs is ignored, this is not pertinent to cognitive radios. A QoS routing protocol is also proposed in [9] that integrates the routing, channel selection and transmission power control aiming to provide higher throughput and constrained end-to-end delay yet the energy constraint is not considered in this paper.

The paper [11] proposes an adaptive cross-layer multi-channel QoS-MAC protocol to support energy efficient, high through-put and reliable data transmission in wireless multi-media sensor networks (WMSNs). This proposed protocol use benefits of TDMA and CSMA to adaptively assign channels and time-slots to active multi-media sensors nodes in clusters. Since the presence of primary users (PUs) is ignored in dynamic spectrum access, this approaches not pertinent to CRs. In [12], this paper proposes a Quality of Service (QoS) routing problem in wireless ad-hoc CRNs. Considering such factor as available time, frequency bands, transmission range, error rate, primary user (PU) interruption rate and transmission range and design a new QoS routing metric for wireless ad-hoc CRNs. Since the shortest path routine does not adhere to the sustained QoS routing as the number of flows grows, this protocol cannot provide performance guarantees to the current flows.

To preserve the QoS for each individual stream Zhou et al. [13] propose a distributed scheduling algorithm (DMDS) for video streaming over multichannel multi-radio devices in wireless networks. DMDS does not employ a CR for dynamic spectrum access and assuming the fixed channels are always available to the nodes. The nodes employ a single radio in this paper, whereas multiple interfaces on a single node and schedules them accordingly by DMDS. This paper implements dynamic spectrum utilization, which is achieved by CR through dynamic spectrum management functions.

In CRSNs, efficient routing pertinent to multimedia application is not yet explored. Where this is the first study that considering the resource constraints along with the dynamic spectrum access, for multimedia routing in CRSNs. The contributions of SCMR are threefold. First, for smooth operations of multimedia delivery it isolates the time and frequency variability of the spectrum i.e., it schedules the channels on the order of longer availability for transmission. Second, by the cluster head the adaption of TDMA frame in a cluster and slot allocation in each source it preserves the QoS requirements of those source hop-by-hop. Third, rather than end-to-end control at the transport layer, SCMR achieves energy efficiency through distributed clustering and ensures the QoS at each intermediate cluster.

3. PROPOSED MODEL

There are *N* number of Secondary Users deployed in the network having the initial transmission range of r m, which are deployed in the field of A m^2 area. Node density ρ is then obtained by N/A. Moreover, nodes are equipped with a single interface module that switches among C traffic channels accessed opportunistically and a pre-defined common control channel (CC). In addition to SUs, there also exists M PUs, which can appear on C channels at any instant with the mean utilization of τ_{on} s and mean silent period of τ_{off} s. We also assume that the channels are not saturated by the PUs such that $M\tau_{on} < C(\tau_{on} + \tau_{off})$ reasonably to concede for SU transmission.

$$S_r^s(t) = \begin{cases} n(t), & if\ H_0 \\ n(t) + S_t(t), & if\ H_1 \end{cases}$$

Assuming non pre-emptive SU transmission, the wireless transceiver either operates in transmission mode or reception. That is, once the SU transmission has commenced, it completes its current frame transmission before releasing the channel. Thus, it might cause interference with the PU or delay its transmission. When the SU observes the spectrum to detect the PU transmission S_t, the received signal $S_r(t)$ takes the following form:

$$P_d = Pr\{Y > \in / H_1\}$$
$$P_f = Pr\{Y > \in / H_0\}$$

The decision statistic Y is obtained from the energy detection algorithm, and is the decision threshold. A Low P_d would result in missing the presence of the PUs with high probability, which in turn increases the interference to the PU. On the other hand, a high P_f would result in low spectrum utilization since false alarms increase the number of missed opportunities. Thus, the availability of a channel c, use a binary variable x_c to represent. For node i sensing channel c, x_c^i = 1 if P_d <0.1 to represent the absence of PUs on channel c; otherwise, it takes 0. SU nodes are configured as single-hop distributed clusters in which a node is elected as a cluster head among a group of neighbours, where as the rest of the neighbours are the members of clusters. A member node transmits data packets to clusters that decide the forwarding path. Thus, by the distributed cluster heads, the transmission is controlled. At different time instants, each node implements both the TDMA and CSMA medium access control (MAC) protocol i.e., at any time t, a node either runs TDMA or CSMA. We assume that the source employs adaptive video coding H.264/MPEG4 that transmits data as a sequence of frames, which are mainly of three types: intra-frame or spatially correlated frame (I-frame), inter-frame predictive or temporally correlated frame (P-frame), and bi-directionally predictive frame (B-frame). In a particular video sequence, the frames are organized to form a group of picture (GOP) of size G that consists of an I-frame followed by F_P number of P-frames and then F_B number of B-frames. Assume that these frames are generated at the rate of λ *(t)* at time instant t with tolerable end-to-end latency of τ_{e2e}. Furthermore, the size of an I-frame is assumed twice the size of a P-frame and four times the size of a B-frame, approximately. However, we assume that P- and B-frames can be transmitted in one slot, where as an I-frame would require two slots for transmission.

SPECTRUM-AWARE CLUSTER-BASED MULTIMEDIA ROUTING

Cluster-based data routing is the potential distributed approach that achieves a suboptimal solution for end-to-end QoS support. In SCMR, SU nodes form a group or a cluster, which have a higher number of commonly available idle channels or higher spectrum rank. A cluster-head is elected among the group that has the highest spectrum energy rank. Cluster-heads employ a hybrid TDMA and CSMA approach for medium access such that the TDMA approach is used within a cluster, whereas the CSMA technique is used in inter-cluster medium access. To maintain QoS, source nodes implement rate-adaptive coding and adopt their data rate according to the slot allocation by the cluster heads for graceful degradation and to avoid re-transmission.

SPECTRUM-AWARE NODES CLUSTERING

The primary criterion in forming cluster-based architecture is the spectrum awareness of nodes apart from their residual energy. In SCR, clustering phase precedes with the spectrum sensing on the potential list of C channels for a fixed sensing period. After gathering spectrum measurements, information sharing phase begins in which each node shares the necessary information with its neighbours that is used in selection of cluster-head. This is achieved by a broadcast Info message that contains the channel vacancy indicator, and statistically computed expected vacancy ratio and availability time. Let v_i(t) be the channel vacancy matrix of node i at time t in which x_c^i(t) takes the binary value 1 if the channel c ∈ C is sensed vacant, otherwise 0. Thus, v_i(t) is formulated as shown in below form

$$v_i(t) = [x_1^i(t)\ x_2^i(t)\ \cdots\ x_C^i(t)]^T$$

Likewise, a_i(t) represents the expected channel availability vector for node i that represents the measurement of mean available time of each vacant channel and is obtained as shown in below form

$$a_i(t) = [a_1^i(t)\ a_2^i(t) \dots a_C^i(t)]^T$$

The mean channel available time is computed as an exponentially weighted average on past channel statistics. We compute the associated channel availability matrix A_j^i of two nodes i and j to communicate with each other as shown in below form

$$A^{ij}(t) = (v_i\ v_j) \times \min\{a_i, a_j\}$$

Where, min is an element-wise minimum operation of two matrices that produces another matrix that has the elementwise minimum values. A node i computes relative spectrum availability rank Υ for a neighbouring node j as shown in below form

$$\Upsilon^{ij}(t) = \frac{1}{c}(1 \cdot A^{ij}(t))$$

where $1 = \{1_1, 1_2, \cdots, 1_C\}^T$ is a binary matrix such that $1_i = 1$. Thus, a node computes its cumulative spectrum energy rank for each of its neighbour as shown in below form

$$\Upsilon_{i(t)} = \sum_{j\in N_i} \Upsilon ij(t) \frac{e_i}{max_{\forall k\in N_i}\{e_k\}} \quad (1)$$

where, N_i represents the set of neighbours of node *i*.

1) **Cluster-head Selection:** The cumulative spectrum energy rank computed above is used as the criterion for the cluster head selection, which is described as follows:

- Every node constructs the matrices v, a in the spectrum sensing phase.
- Nodes report the spectrum information and their residual energy in the broadcast Info message during cluster formation phase. It can be seen that v contains binary values and therefore the field size is only in the order of C bit. Moreover, a is approximated in the order of contention slot period set to usually 10s of μ sec that would require 16 bit making the field of C × 16 bits.
- A node computes its cumulative spectrum energy rank Υ_i(t) with each of its neighbour using (1).
- Node i also computes the rank Υ_k(t) or all of its neighbours k ∈N *i*.
- It compares its rank against all the neighbours rank and if it is found among the three highest ranks then it becomes a potential cluster-head.
- All the nodes synchronize their timers with their cluster heads upon the arrival of CH message and hence, the data transmission phase begins. Note that the synchronization error occurs due to the propagation delay, which is small in the order of microseconds and compensated by leaving a transmission gap of a contention slot (10 μs).

1) **Channels Selection and Scheduling:** Channel scheduling algorithm is run by the cluster-head to schedule the use of channels over the TDMA frame by the members acquiring time slots. Note that the time slots are allocated in a round robin fashion. We define expected availability ratio (EAR) y_i^c(t) for determining the average PU presence and deducing the spectrum sensing outcome for channel *c* by sensor node *i*. The EAR vector Y_i(t) for sensor *i* at time *t* is obtained as shown in below form

$$Y_i(t) = (1-\alpha)\, a_i(t) + \alpha \cdot y_i(t-1) \quad (2)$$

Where, α is the forgetting factor that decides the contribution of previous states to current state. Cluster head sorts the vector in the descending order of EAR and assigns the channel c for which x_c^i =1 and has the highest value in the vector. Then it schedules them along with the slot in its TDMA schedule. However, if there is no channel with x_c^i =1 for a node, i.e., no channel is detected vacant common to the cluster-head and member, and then it selects the one with the highest EAR value subject to the threshold y_i^c(t) ≥ EAR_{th}. The value of EAR_{th} threshold is set corresponding to the TDMA frame.

ROUTING

Routing in SCR is performed in proactive fashion since the cluster-heads are the only responsible nodes to establish route with the sink and also K$\ll$N. This incurs much lesser overheads than if all the nodes set up routes individually. After the cluster formation, the routing algorithm runs as follows

- Cluster-head broadcasts the route request (CH-RREQ) message. Member nodes receive the request and broadcast it further after waiting for the random back off time. If a member node overhears CH-RREQ transmitted by another member m_i^u of the same cluster k_u then it cancels its backoff timer and ignores the message.
- Nodes of different cluster k_v, receiving the CH-RREQ, run a short backoff random timer. A node m_j^v whose timer expires earlier broadcasts the CH-RREP message, if the route is found in its cache, on the behalf of its cluster-head k_v. Otherwise, it forwards the CH-RREQ message to its cluster-head after waiting for long back off time. If k_v, keeps the route to the sink then it broadcasts the CH-RREP message containing the number of cluster heads on the path along with the minimum remaining clustering period. All the members of k_v, cache the route reply information and only the node m_j^v broadcasts the CH-RREP message. If k_v does not contain route information then it also forwards the CH-RREQ message.
- All the members of k_u receiving CH-RREP message from m_j^v cache the route information and only m_i^u forwards the CH-RREP message to the cluster-head k_u.
- Once the route is found, cluster-head announces the start of request propagation phase. Nodes

queuing data for transmission, transmits the data request message (MDREQ) containing the required number of slots to be transmitted and also the cached routing information, if exist, learned in the route establishment phase.

- If the data request message does not contain route information or the nodes learned route is not the preferred route then it is assumed that such nodes are farther from the forwarding cluster and their data is passed through the cluster-head by allocating TDMA slots. Otherwise, cluster-head does not allocate slots in its TDMA frame and such nodes are allowed to directly transmit through the cached members of forwarding cluster.
- At the end of request propagation period, cluster-head prepares its TDMA schedule along with the spectrum schedule and broadcasts it. Member nodes receiving this message synchronize with the cluster-head and TDMA frame commences.

Thereafter, every node transmits in its specified time slot on a given channel.

4. CONCLUSION

This paper proposes a spectrum-aware cluster-based multimedia routing (SCMR) protocol for CRSN, providing energy efficiency with dynamic spectrum access. In SCR, SU nodes are clustered based on their residual energy and relative spectrum awareness. Here, each node computes a joint energy spectrum rank in which a high rank node is selected as a cluster-head that controls the spectrum access and routing of data. To minimize the delay by exploiting spectrum diversity, routing is integrated with a hybrid TDMA and CSMA medium access protocol to relay intra-cluster and inter-cluster packets respectively, thus allowing to simultaneously perform intra-cluster and inter-cluster routing. Moreover, its optimal clustering provides energy-efficient multimedia delivery with the desired QoS support.

REFERENCES

[1] H. Donglin, M. Shiwen, Y. T. Hou, and J. H. Reed, "Scalable video multicast in cognitive radio networks," IEEE J. Sel. Areas Commun., vol. 28, no. 3, pp. 334–344, Apr. 2010.

[2] F. R. Yu, B. Sun, V. Krishnamurthy, and S. Ali, "Application layer QoS optimization for multimedia transmission over cognitive radio networks," Wireless Netw., vol. 17, no. 2, pp. 371–383, Feb. 2011.

[3] S. Hsien-Po and M. van der Schaar, "Queuing-based dynamic channel selection for heterogeneous multimedia applications over cognitive radio networks," IEEE Trans. Multimedia, vol. 10, no. 5, pp. 896–909, Aug. 2008.

[4]X. L. Huang, G. Wang, F. Hu, and S. Kumar, "The impact of spectrum sensing frequency and packet-loading scheme on multimedia transmission over cognitive radio networks," IEEE Trans. Multimedia, vol. 13, no. 4, pp. 748–761, Aug. 2011.

[5] Y. Chen, Y. Wu, B. Wang, and K. J. R. Liu, "Spectrum auction games for multimedia streaming over cognitive radio networks," IEEE Trans. Commun., vol. 58, no. 8, pp. 2381–2390, Aug. 2010**.**

[6] A. Bhattacharya, R. Ghosh, K. Sinha, and B. P. Sinha, "Multimedia communication in cognitive radio networks based on sample division multiplexing," in Proc. 3rd COMSNETS, Jan. 2011, pp. 1–8.

[7] O. B. Akan, O. B. Karli, O. Ergul, "Cognitive Radio Sensor Networks," IEEE Network, vol. 23, no.4, pp. 34-40, July 2009.

[8] K. R. Chowdhury and I. F. Akyildiz, "CRP : A Routing Protocol for Cognitive Radio Ad Hoc Networks," IEEE Journal on Selected Areas in Communications, vol. 29, no. 4, pp. 1-11, 2011.

[9] Y.-F. Wen, W. Liao, "On QoS Routing in Wireless Ad-Hoc Cognitive Radio Networks," Proc. of 71st IEEE Vehicular Technology Conference (VTC'10), pp.1-5, 16-19 May 2010.

[10] G. H. E. Fard, M. H. Yaghmaee, R. Monsefi, "An Adaptive Cross-Layer Multichannel QoS-MAC Protocol for Cluster Based Wireless Multimedia Sensor networks,", Proc. of Ultra Modern Telecommunications & Workshops (ICUMT'09), pp.1-6, 12-14 Oct. 2009.

[11] G. H. E. Fard, M. H. Yaghmaee, and R. Monsefi, "An adaptive crosslayer multichannel QoS-MAC protocol for cluster based wireless multimedia sensor networks," in Proc. ICUMT Workshops, Oct. 12–14, 2009, pp. 1–6.

[12] Y.-F. Wen and W. Liao, "On QoS routing in wireless ad-hoc cognitive radio networks," in Proc. IEEE 71st VTC, May 16–19, 2010, pp. 1–5.

[13] L.Zhou, X.Wang,W.Tu, G.Mutean, and B.Geller, "Distributed scheduling scheme for video streaming over multi-channel multi-radio multi-hop wireless networks," IEEE J. Sel. Areas Commun., vol. 28, no. 3, pp. 409–419, Apr. 2010.

BIOGRAPHIES

Mr. Raghavendra L R
Asst. Professor, Dept. of ECE, BGS Institute of Technology, Karnataka, India

Mr. Anandaraju M B
HOD, Dept. of ECE, BGS Institute of Technology, Karnataka, India

Amulya M K
Dept. of ECE, BGS Institute of Technology, Karnataka, India

Chanchala M
Dept. of ECE, BGS Institute of Technology, Karnataka, India