Multimedia Data Communication Through Cognitive Radio Networks

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Outline

Outline

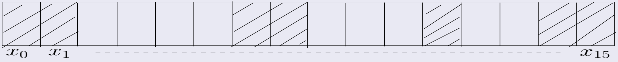
Bandwidth Management and Cognitive Radio Networks

- Wireless Communication: the fastest growing industry in telecommunication.
- Rapid growth of 802.11 hotspots in uncoordinated fashion.
- Increasing trend of multimedia communication.
- Problem of maintaining QoS for multimedia signal.
- Limited availability of radio spectrum.
- The available radio spectrum is not utilized uniformly.
- *CR* technology for increasing the effective utilization of the available spectrum.
    - Opportunistic sharing of the spectrum using *white spaces*.

Outline

Problem Statement

Spectrum Divided into Channels(Unused Channels shown as White)



- A part of the spectrum divided into 16 channels and marked as $x_0, x_1, \cdots, x_{15}$.
- Each of these channels having same bandwidth, B_{min}, equal to the minimum bandwidth required among different types of multimedia signals.
- Let a video signal transmission need eight consecutive x_i's.
- **Problem :** There is no continuous band consisting of eight consecutive channels though a total of nine randomly distributed channels are still available.

Problem Statement cont.

Problem

To devise an appropriate technique for the transmission of the given multimedia signal through eight of these available nine channels, without compromising the *QoS* at the receiving end.

Routing in Cognitive Radio Networks

- In a general *CRN*,
  - channels may have different bandwidths,
  - may have varying propagation characteristics and
  - may be available for unequal time durations.
- In a dynamic *CRN*,
  - *PU*s may use the channels for intermediate durations,
  - channel switching may be required and
  - routs may be changed.
- Distance minimization techniques or channel selection approaches to path assignment may not yield optimal results.

Sequential and joint path-channel selection algorithms that minimize the hop count and maintain conflict free channels constitute a challenging research problem in *CRN*s.

Outline

Our Contribution

- In a fragmented spectrum, even when no contiguous white space of required bandwidth is available, communication is possible over the required number of fragmented channels.
- We use the technique of *Sample Division Multiplexing* (*SDM*).

Our Contribution cont.

- In *SDM* a multimedia signal is decomposed into a number of sample sets, each transmitted over a bandwidth of B_{min}.
- Each sample set is transmitted through one available channel in the white space such that different sample sets occupy different channels in the available spectrum holes.
- At the receiver end, all the packets are used to reconstruct the original signal.
- Suitable algorithms for channel sensing and allocation avoiding the hidden node problem and possible collision are used.

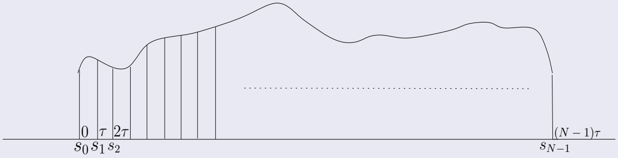
Our Contribution cont.

- There is a need to design new routing protocols that
  - considers the spectrum sensing function,
  - spectrum decision,
  - MAC layer spectrum access technology and
  - end-to-end performance requirements for *CRN*s.
- A novel scheme for multi-hop routing in a *CRN* for multimedia communication has been proposed,
  - even when a contiguous band of required width is not available for any hop in the route.
  - scheme is based on an extension of the idea of *SDM*.

Outline

Sample Division Multiplexing

Samples from the Signal



Consider a band-limited signal of a bandwidth W.

- Sampling Frequency $2W$.
- Samples are $s_0, s_1, \cdots, s_{N-1}$.
- Number of samples N taken over time period T.
- Sampling interval of $\tau = \frac{1}{2W}$.
- Thus, $T = N\tau$.

Sample Division Multiplexing cont.

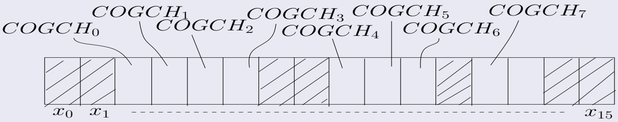
- Let required number of available channels to maintain QoS be n.
- Partition of the N samples in n subsets, $SS_0, SS_1, SS_2, \cdots, SS_{n-1}$

$$SS_i = \{s_j | j = i \mod n, 0 \leq i, j \leq n-1\} \quad (1)$$

- Note that in each SS_i, the samples are separated by $n\tau$,
- Transmission bandwidth, $\frac{W}{n} \leq B_{min}$.

Sample Division Multiplexing cont.

Utilized Spectrum with Sample Division Multiplexing



- $COGCH_i$ are Cognitive Channels, $i = 0, 1, \cdots, n-1$.
- Corresponding to each time frame of a suitable duration T, samples are taken in the set SS_i to form a data sub-packet SP_i.
- The header of each SP_i contains the identity of the time frame and the sub-packet number (SPN) equal to i.

Outline

System Model

Assumptions

1. All *Secondary Users* (*SU*) have the same priority.
2. All *Primary Users* (*PU*) have the same priority which is greater than that of a *SU*.
3. Any given node in the system has the maximum capability of providing some m number of channels.
4. A *Common Control Channel* (*CCC*) is used for coordination between the various *SU*s, the communications being done in discrete time slots.

Outline

Beginning of Transmission

1. Connection establishment process consists of *Sensing* and *Allocation*.
2. When the transmitter buffer becomes full, a status bit B_{Tx} is set to 1 indicating that this node wants to transmit a message.
3. The transmitter needs m channels to transmit its message.
4. A node can always sense the channels used by all of its 1-distance neighbors for transmission.
5. While allocating a channel, the hidden node problem is avoided.

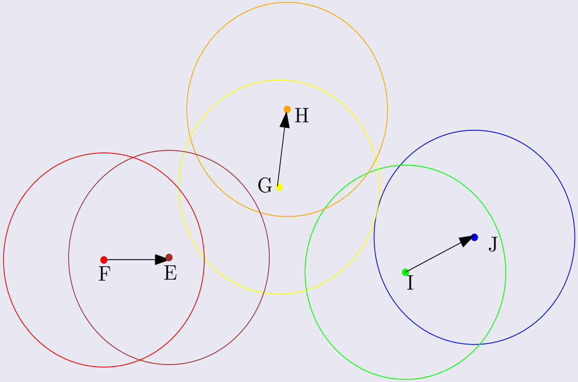
Beginning of Transmission cont.

Steps

1. Grab the *CCC* and reserve m channels at the receiving node.
2. Sense the used channels of the 1-distance neighbors.
3. Out of the free channels, choose m channels not being used by any of its 1-distance neighbors in receiving messages from some 2-distance neighbors (to avoid hidden node problem).
4. Allocate the m free channels to the destination node.

Proposed Algorithms and Processes

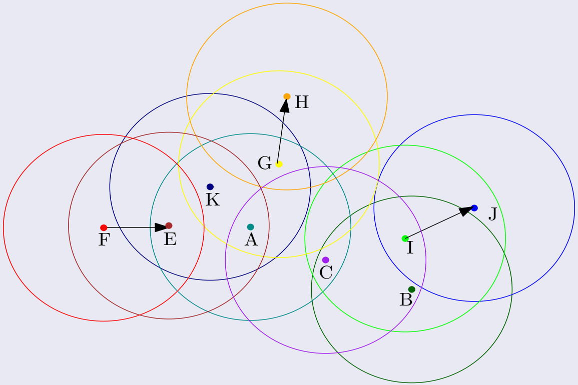
Nodes with their Respective Sensing Regions



E, F, G, H, I and J are different CRN nodes.

Proposed Algorithms and Processes cont.

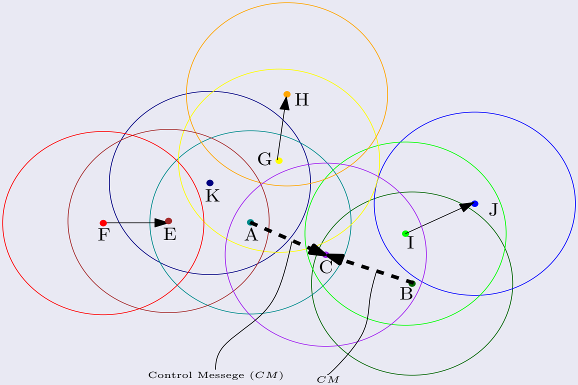
Nodes with their Respective Sensing Regions



A, B, C and K are new nodes in the network.

Proposed Algorithms and Processes cont.

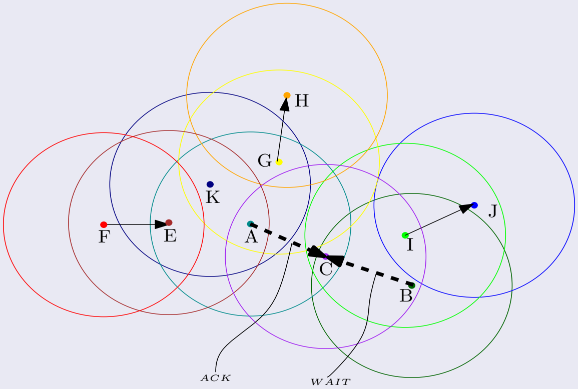
Nodes with their Respective Sensing Regions



A and B wants to start communication with node C.

Proposed Algorithms and Processes cont.

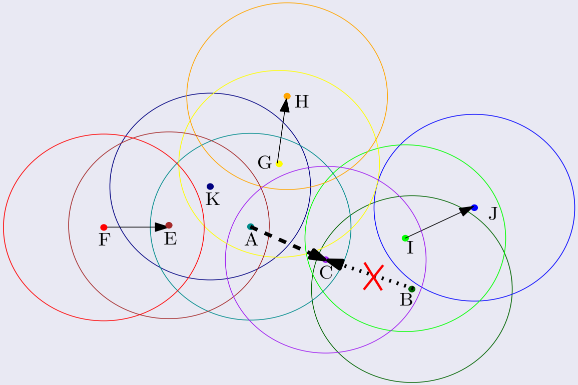
Nodes with their Respective Sensing Regions



A wins the race.

Proposed Algorithms and Processes cont.

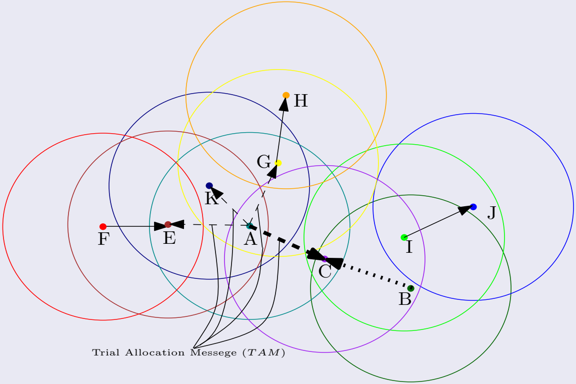
Nodes with their Respective Sensing Regions



B waits in a queue.

Proposed Algorithms and Processes cont.

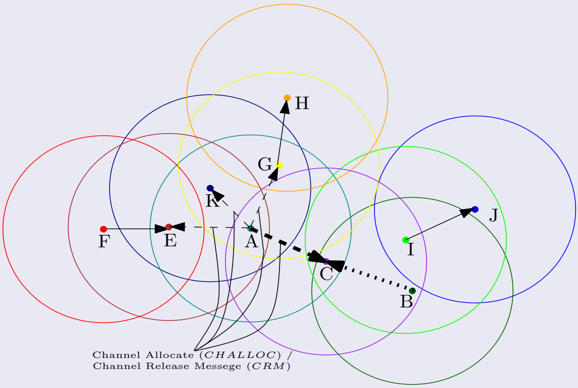
Nodes with their Respective Sensing Regions



A wants to allocate communication channels for sending multimedia data.

Proposed Algorithms and Processes cont.

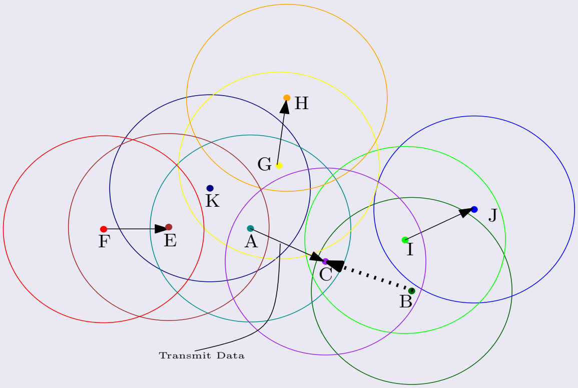
Nodes with their Respective Sensing Regions



A allocates the data channels.

Proposed Algorithms and Processes cont.

Nodes with their Respective Sensing Regions



A starts communication with C.

End of Transmission

Steps

1. The transmitting node will release all the data channels using channel release message.
2. To abort a transmission, all the channels allocated to both transmitting and destination nodes are released.
3. When receiving node releases one or more channels the next channel reservation request from its waiting queue is considered on *First-Come-First-Serve* basis.

Outline

Performance Analysis

Maximum Number of Nodes within 2-distance

- Total number of nodes within distance 2 from a node is given by,

$$N_2 \leq \Delta + \Delta(\Delta - 1) \leq \Delta^2 \tag{2}$$

where Δ is the maximum node degree in the *CRN*.

Performance Analysis cont.

Probability of Getting Channels Free

- The probability of any one channel being free can be expressed as,

$$p_1 = \frac{C - b_t}{C} \tag{3}$$

  where C is the total number of channels in the whole spectrum and b_t is the actual average demand of N_2 nodes.

- The probability of success of a particular user in getting all n channels free in one single attempt is given by,

$$p_n = \frac{\binom{C-b_t}{n}}{\binom{C}{n}} = \frac{(C-n)!(C-b_t)!}{C!(C-b_t-n)!} \tag{4}$$

  where n is the number of channels required by a node, $n > 1$.

Performance Analysis cont.

Attempts for Getting Channels

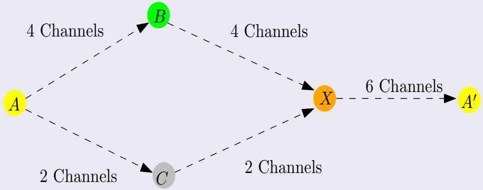
- Getting a free channel in exactly after k attempts is equal to $p_1(1-p_1)^{k-1}$.
- The maximum number of attempts required for getting all free channels when all channels work in parallel is given by,

$$\alpha_{max} = \sum_{k \geq 1} k p_1 (1-p_1)^{k-1} = \frac{1}{p_1} = \frac{C}{C-b_t} \tag{5}$$

Outline

Problem Statement

Splitting of channels for a network



Suppose a node A needs a total bandwidth of 6 B_{min} corresponding to 6 channels, each of bandwidth B_{min}, to transmit some multimedia data to another node A'.

Problem Statement contd.

- Let *DN* number of channels required for certain multimedia communication.
- Let *AN* denote the available number of channels of a node.
- Transmit a multimedia signal requiring *DN* channels even when
  - there does not exist any single route in which each node will have $AN \geq DN$,
  - but there exist multiple routes so that the sum of the *AN*s in all these routes is at least equal to *DN*.
- To the best of our knowledge, there is no existing techniques in the literature that can achieve this in *CRN*s.

Outline

Outline

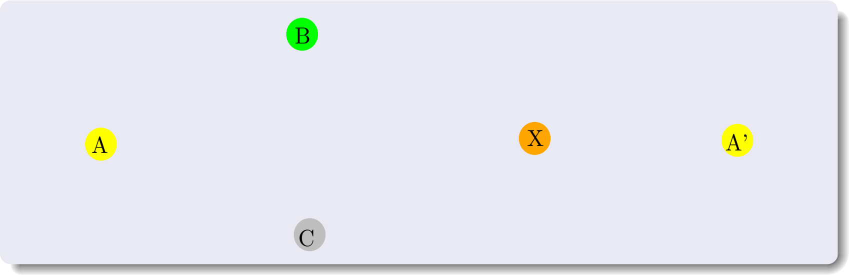
System Model

Assumptions

- All *PU*'s have the same priority.
- All *SU*'s have the same priority, less than the priority of a *PU*.
- There is a *CCC* for coordinating the various *SU*s.
- Communication through *CCC* are effected in discrete time slots as collision-free *Bit-Map* protocol.
- Time slot is δ_{max}, where δ_{max} is the maximum node-degree of the network graph *G*.
- Each node has a unique node *id* and knows the *id*'s of every other node of the network.
- Network graph is strongly connected.
- Topology remains unchanged during initialization process.

System Model cont.

- B_{Tx} of a node is 1 means this node wants to transmit a message.
- A node u is called a 1-distance neighbor of a node v if u falls under the communication range of node v, denoted as $v \rightarrow u$.
- The communication range of a node depends on its maximum available power.
- Since different nodes may have different maximum available power, an edge $v \rightarrow u$ does not necessarily imply an edge $u \rightarrow v$.
- There will be an undirected edge between u and v if both $v \rightarrow u$ and $u \rightarrow v$ exist.
- The proposed routing protocol consists of two phases :
  - exploring *AN* of all nodes in the network and
  - find and reserve routes.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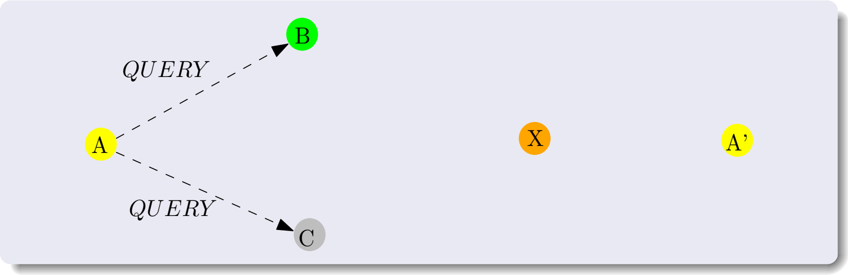
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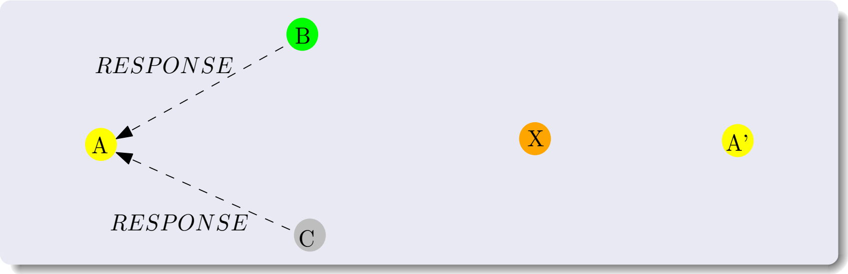
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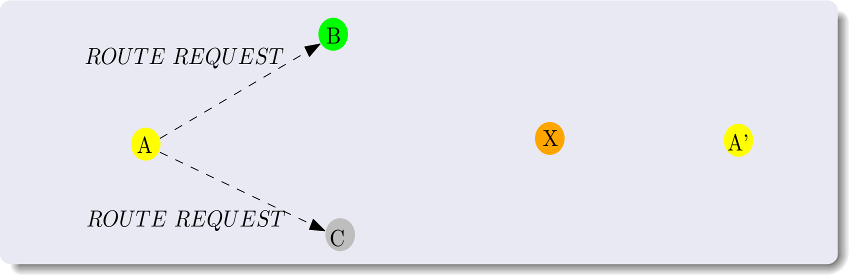
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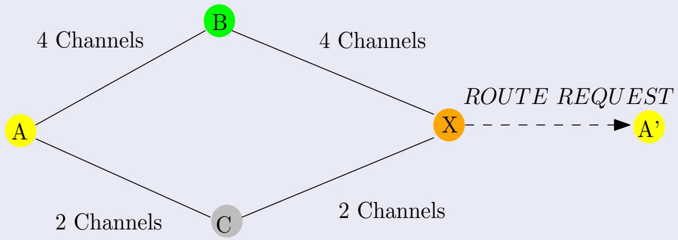
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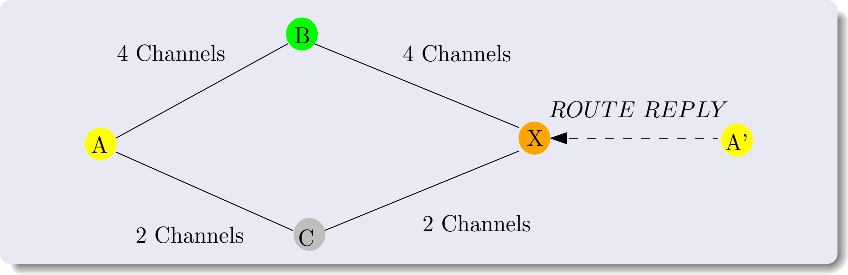
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2 Channels
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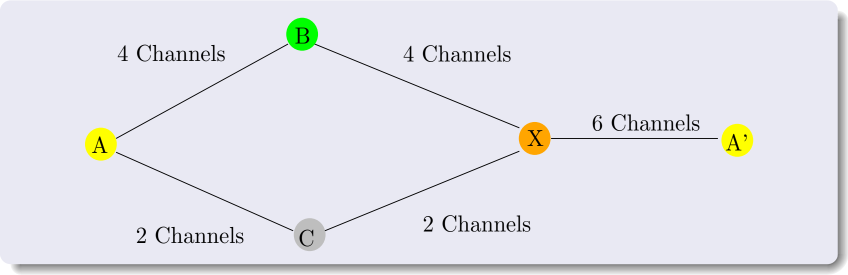
2 Channels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4 Channels
4 Channels
6 Channels
2 Channels
2 Channels

Max-Flow Algorithm

Find and Reserve Routes

- Now we need to find the routes, if any, and reserve them.
- We actually map this problem to the network flow problem.
- We run the Ford-Fulkerson max-flow algorithm to find the maximum possible flow.
- If this maximum flow is less than DN, then routing can not be possible.
- If the maximum flow is greater than equal to DN, routes can be found with total flow DN from the source.
- The source node starts the channel reservation procedure to reserve the desired number of channels along the route(s) as computed by the algorithm.

Outline

Result 1 :

The initialization time T_{SD} for exploring the available number of channels between every pair of nodes is $O(\Delta\delta_{max})$, where δ_{max} is the maximum node-degree and Δ is the diameter of the network graph G.

Result 2 :

The time complexity of the proposed protocol is $O(pf + T_{SD})$, where p is the number of edges in the graph G, f is the maximum flow in G and T_{SD} is the initialization time for exploring the available number of channels between every pair of nodes.

- The source node may have to wait for $O(\delta_{max})$ time to get the *RESPONSE* message from all of its 1-distance neighbors.
- To know the edge capacity from all of its 1-distance neighbors, at most $O(\delta_{max})$ message exchange is required.

Ealier Work

- Multi-hop multi-path routing in a *CRN* for multimedia communication has been proposed even when a contiguous band of required width is not available for any hop in the route. Complexity is $O(pf + T_{SD})$.
  - p is the number of edges in the graph G
  - f is the maximum flow in G
  - T_{SD} is the initialization time for exploring the available number of channels between every pair of nodes, where complexity of T_{SD} is $O(\Delta\delta_{max})$
    - δ_{max} is the maximum node-degree
    - Δ is the diameter of the network graph G
- Scheme is based on an extension of the idea of Sample Division Multiplexing (*SDM*).

Outline

Outline

System Model

Assumptions

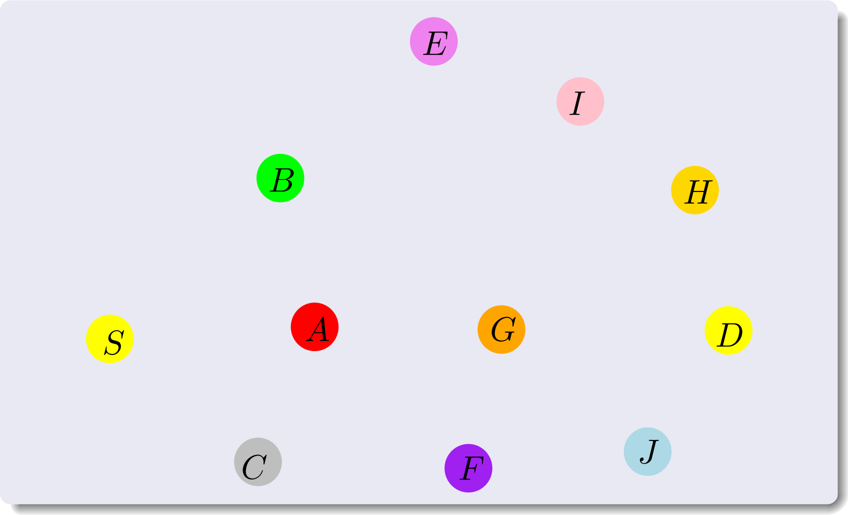
- All *PU*'s have the same priority.
- All *SU*'s have the same priority, less than the priority of a *PU*.
- There is a *CCC* for coordinating the various *SU*s.
- Communication through *CCC* are effected in discrete time slots as collision-free *Bit-Map* protocol.
- Each node has a unique node *id*.
- Topology remains unchanged during initialization process.

System Model cont.

Removed assumptions

- Every node knows the *id* of every other node of the network.
- Network graph is strongly connected.

- A node u is called a 1-distance neighbor of a node v if u falls under the communication range of node v, denoted as $v \rightarrow u$.
- There will be an undirected edge between u and v if both $v \rightarrow u$ and $u \rightarrow v$ exist.
- We need three control messages *ROUTE REQUEST*, *ROUTE REPLY* and *BUSY*.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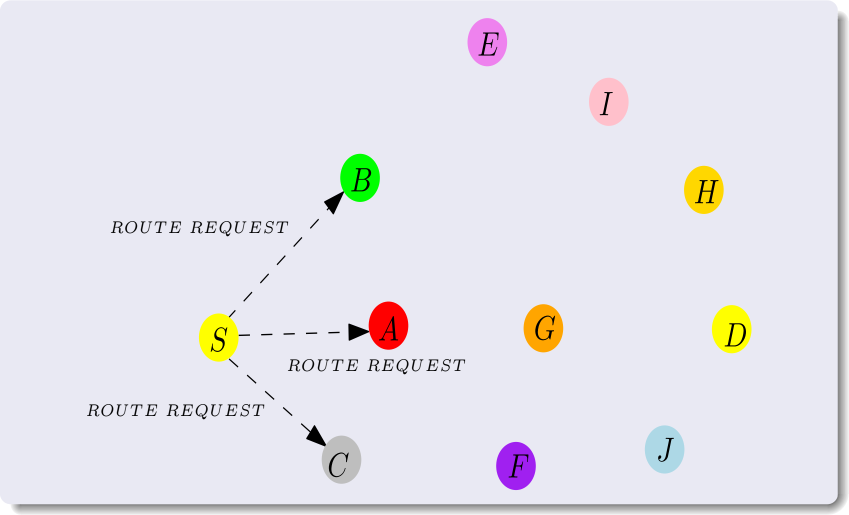
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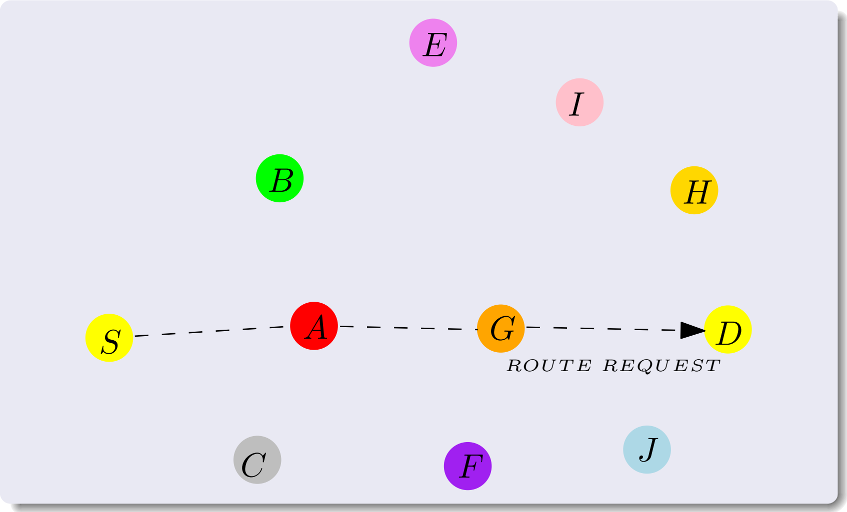
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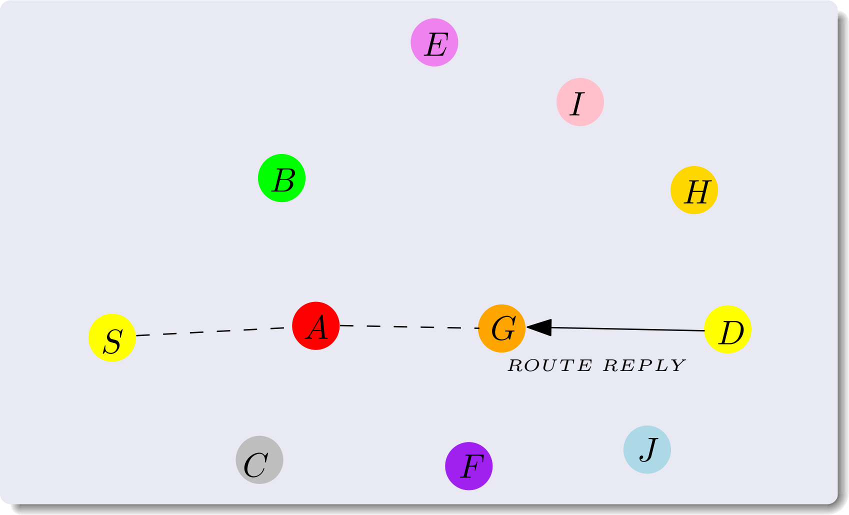
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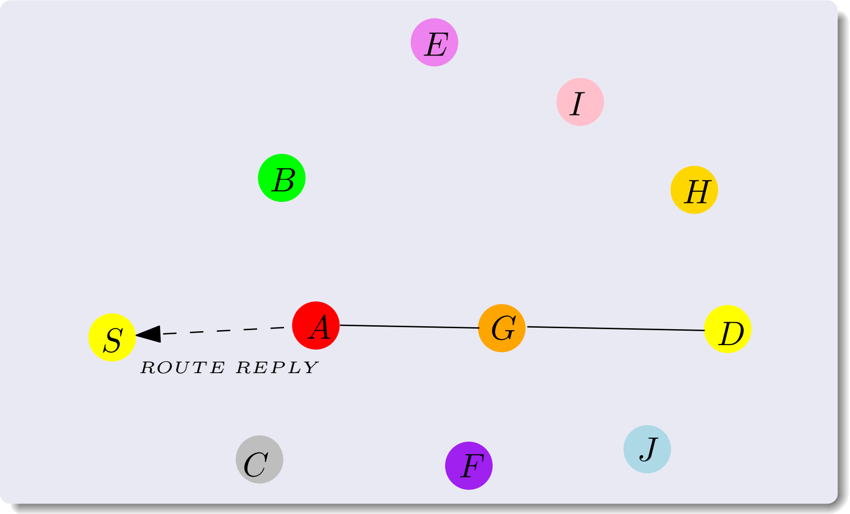
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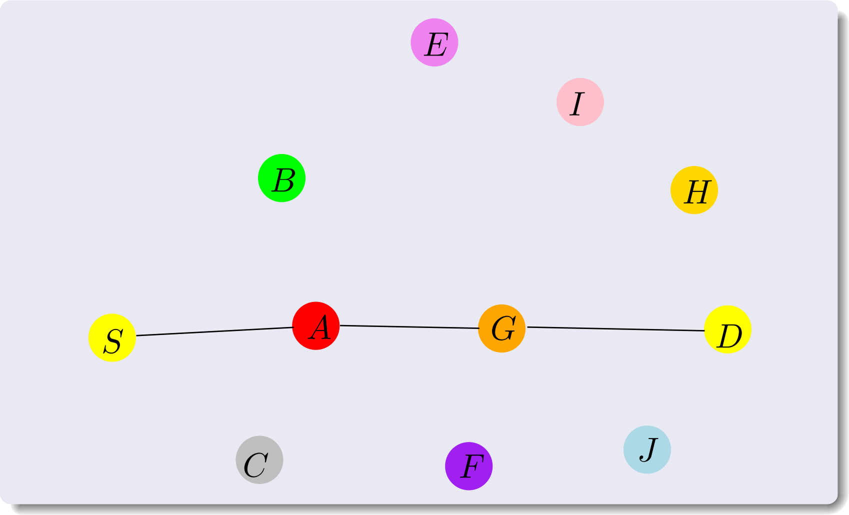
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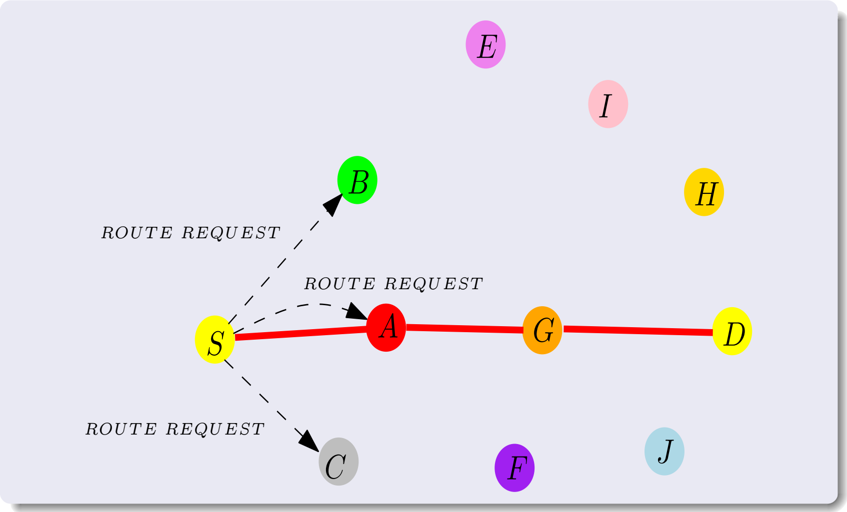
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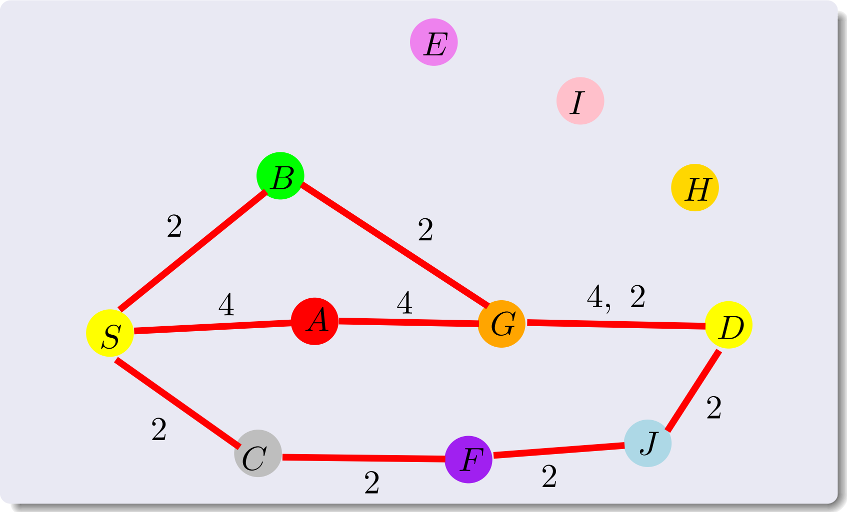
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Outline

Theorem

The worst-case time complexity of the proposed protocol is $O(|E| \times DN)$, where E is the number of edges in the network and DN is the demand number of channels for communicating the multimedia signal.

Outline

Conclusion

- We proposed a novel technique of SDM for communicating a multimedia signal in a cognitive radio network without defragmenting the white spaces.
- The technique is based on finding a set of non-contiguous white spaces whose total width will be equal to the required bandwidth of the multimedia signal.
- We sub-divide the samples from the original signal in the time domain, form sub-packets with these subsets of samples and transmit these sub-packets through the set of channels so found.

Conclusion

- A multi-path routing protocol for multimedia communication in a *CRN* has been proposed.
  - exchanging control messages it explores the available number of channels between every pair of 1-distance neighbor nodes.
  - Max-flow algorithm finds the route for the required number of channels.
- Time complexity of our protocol is $O(pf + T_{SD})$.
- Simulation results show that splitting the message and routing them along multiple paths leads to an improved performance.

Conclusion

- An on-demand fully distributed multi-path routing protocol for multimedia communication in a *CRN* has been proposed.
- We have relaxed some strong assumptions.
- Worst-case time complexity of our protocol is $O(|E| \times DN)$.
- Simulation results establish the fact that the average time complexity of our proposed algorithm gives us an improved performance.
- Finding a tight upper bound on the worst-case time complexity of our proposed algorithm is an open problem.

Thank You !