

Opportunistic Data Dissemination in Ad-Hoc Cognitive Radio Networks

PhD Thesis Defense
of
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Problem Statement

- Multi-Hop Cognitive Radio Ad-Hoc Networks
 - Primary Radio (PR) Nodes
 - Cognitive Radio (CR) Nodes
 - Lack of centralized entity
- Main Goal: How to perform robust data dissemination in Multi-Hop Cognitive Radio Ad-Hoc Networks?
 - That cause less harmful interference to PR nodes
 - That try to maximize the chances that the message is delivered to the neighboring CR nodes

Outline of the Presentation

- Introduction to Cognitive Radio Networks
- Motivation: Data Dissemination in Cognitive Radio Networks
- Contributions:
 - 1st: Channel Selection Strategy SURF
 - 2nd: Impact of Primary Radio Nodes Activity Pattern
 - 3rd: Applicability of SURF
- Conclusion and Future Work

INTRODUCTION TO COGNITIVE RADIO NETWORKS

Spectrum Occupancy

...Most Spectrum Is Unused!

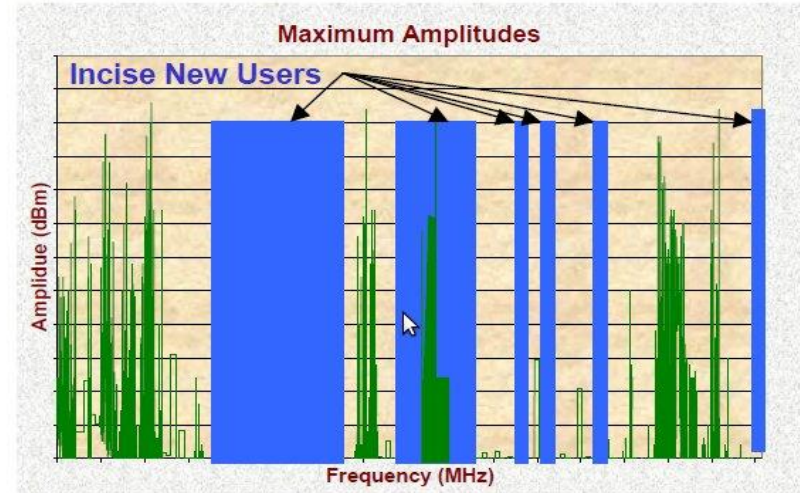
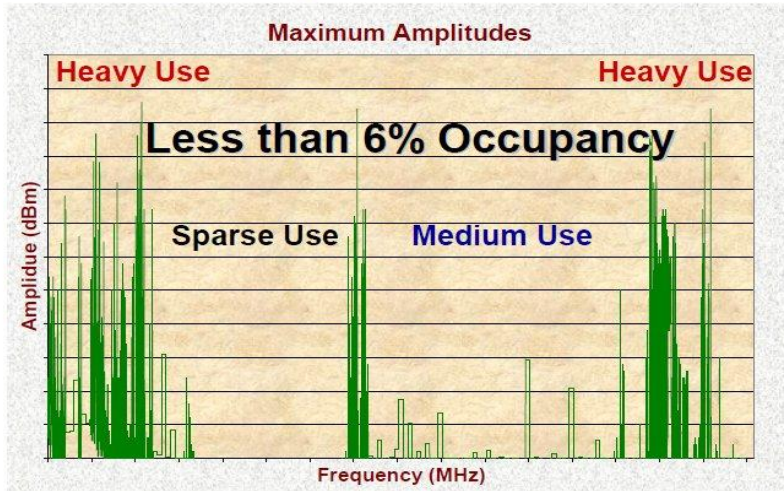


Figure taken from [1]

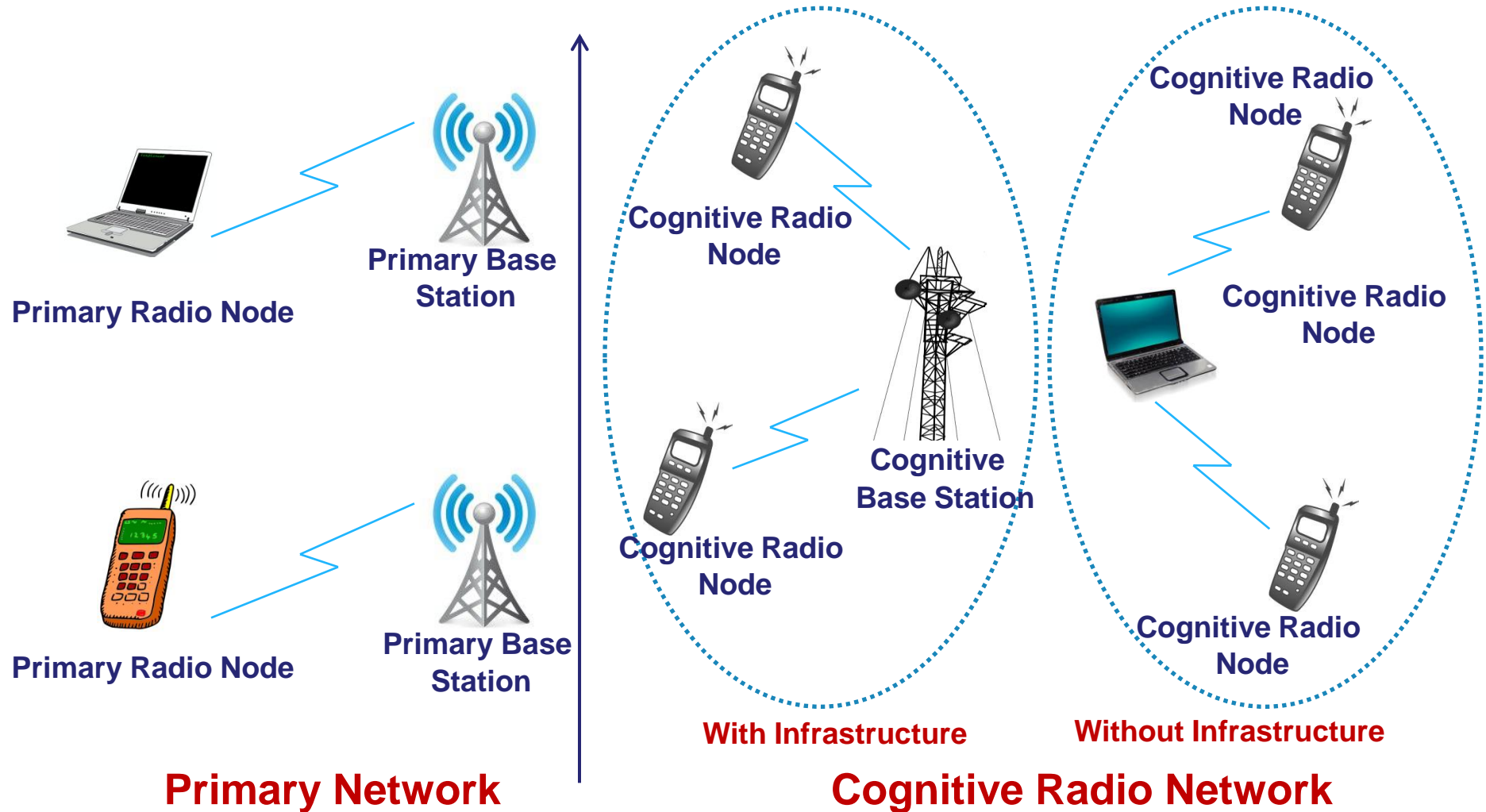
- Due to:
 - Fixed spectrum assignment policy
 - Limited available spectrum in today's wireless network
- Results In:
 - Inefficiency in spectrum usage
 - Creation of Spectrum Holes

[1] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey," Computer Networks, vol. 50, Issue 13, pp. 2127 – 2159, 2006.

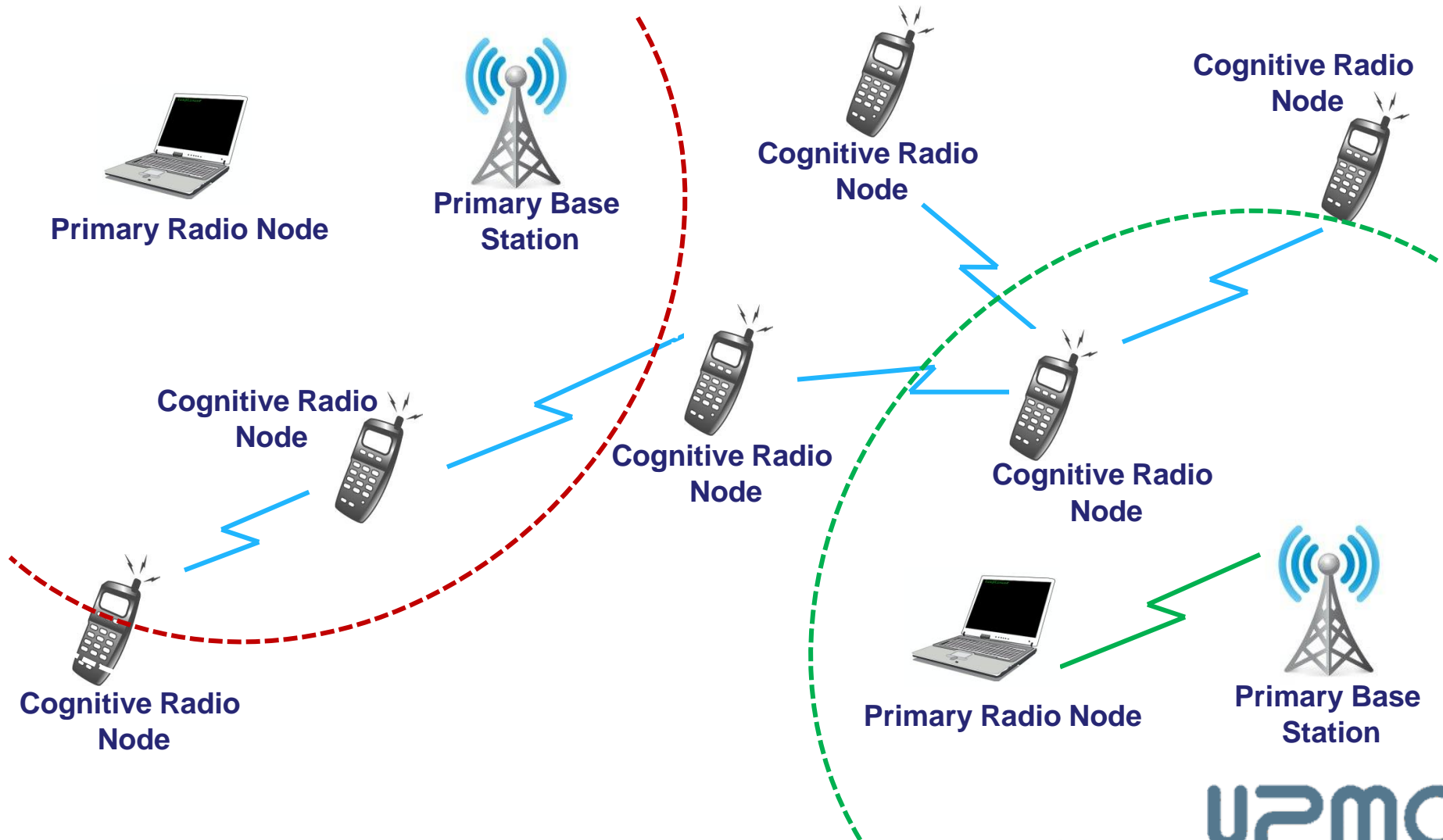
Cognitive Radio (CR) Network and its Functionalities

- Cognitive Radio nodes opportunistically exploit the licensed band
- Main functions:
 - ***Spectrum Sensing***: Detect unused spectrum and presence of licensed users
 - ***Spectrum Management***: Select best available channel
 - ***Spectrum Sharing***: Coordinate access to this channel with other users
 - ***Spectrum Mobility***: Vacate the channel when a licensed user is detected and maintaining seamless communication

Cognitive Radio Network Architecture

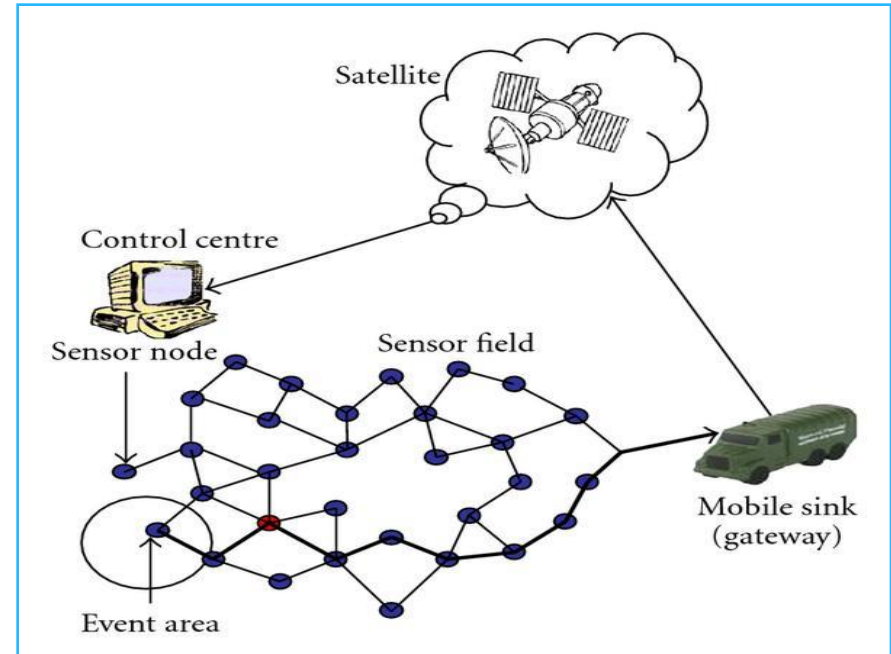
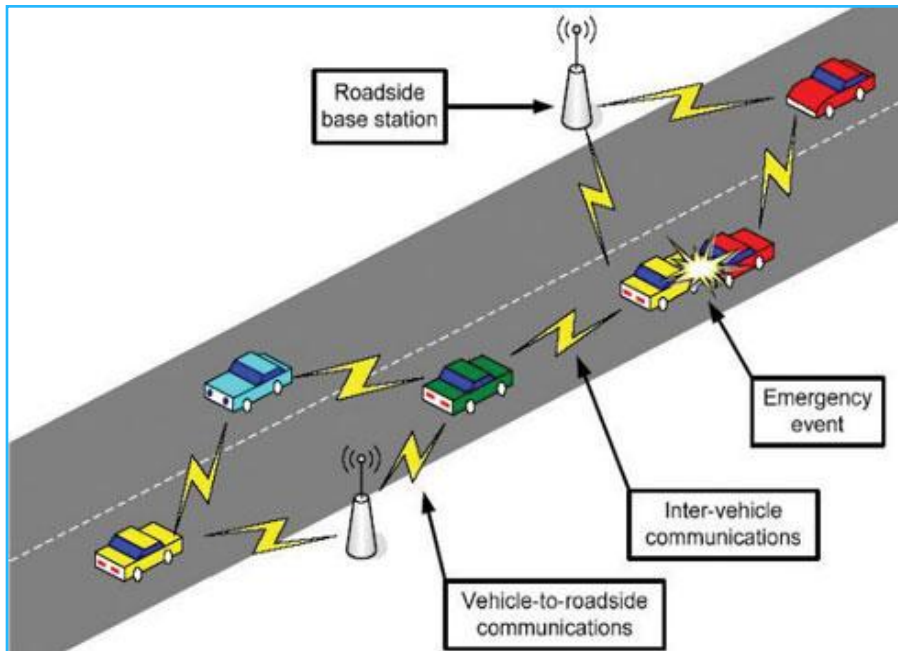


Multi-Hop Cognitive Radio Ad-Hoc Network



MOTIVATION: DATA DISSEMINATION IN COGNITIVE RADIO NETWORKS

Data Dissemination in Traditional Wireless Networks and in CRNs



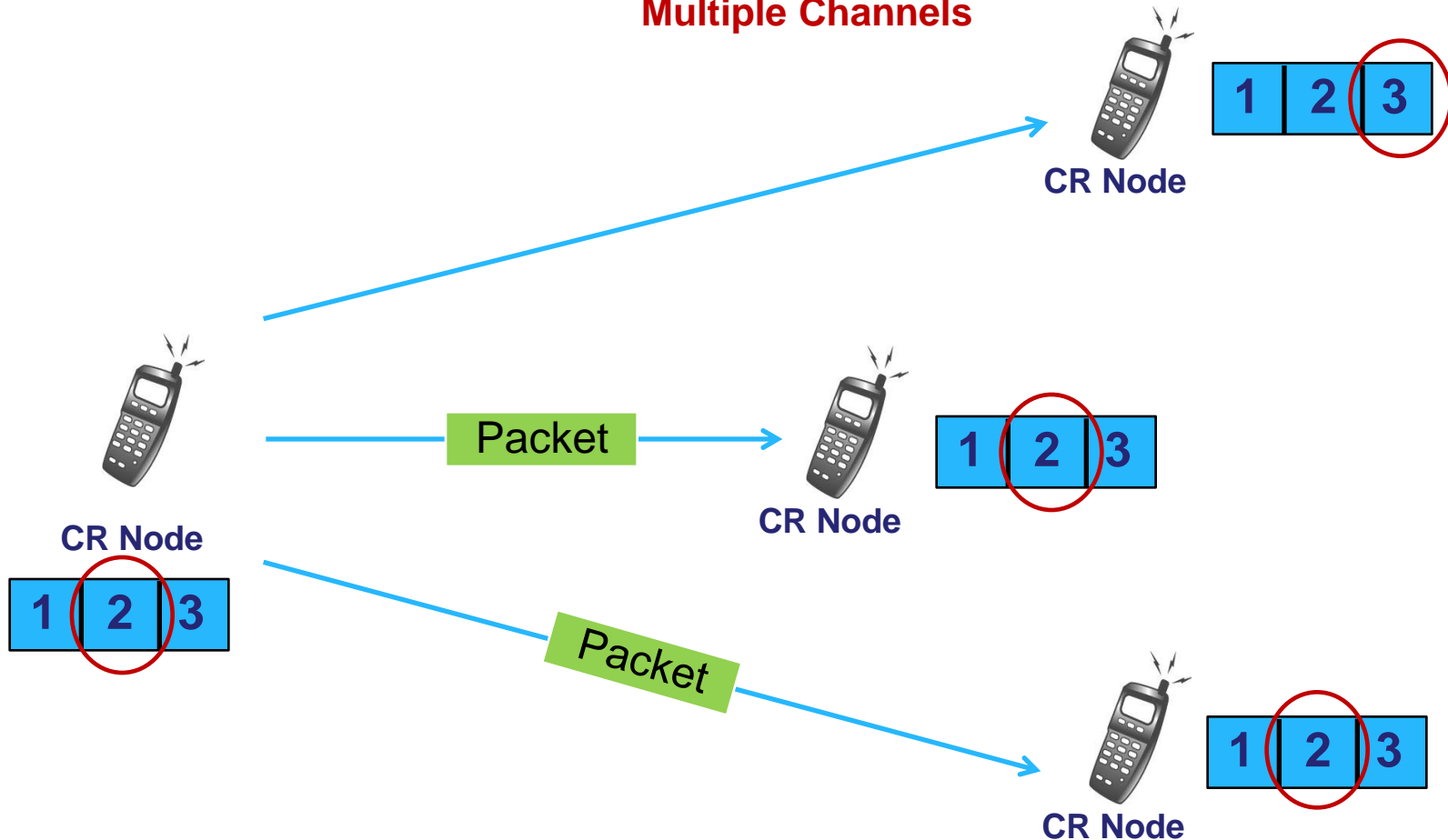
- Challenges in wireless networks:
 - Message losses, Collisions, Broadcast storm problem etc.
- In CR Networks, data dissemination can be used for:
 - Emergency messages, alerts and publicity messages

Why Data Dissemination is Challenging in Multi-Hop CRNs?

- Frequency Agility
- Intermittent Connectivity
- Primary Radio Activity
 - CR transmissions should not degrade the reception quality of Primary Radio (PR) nodes
 - CR node should immediately interrupt its transmission whenever any neighboring PR activity is detected

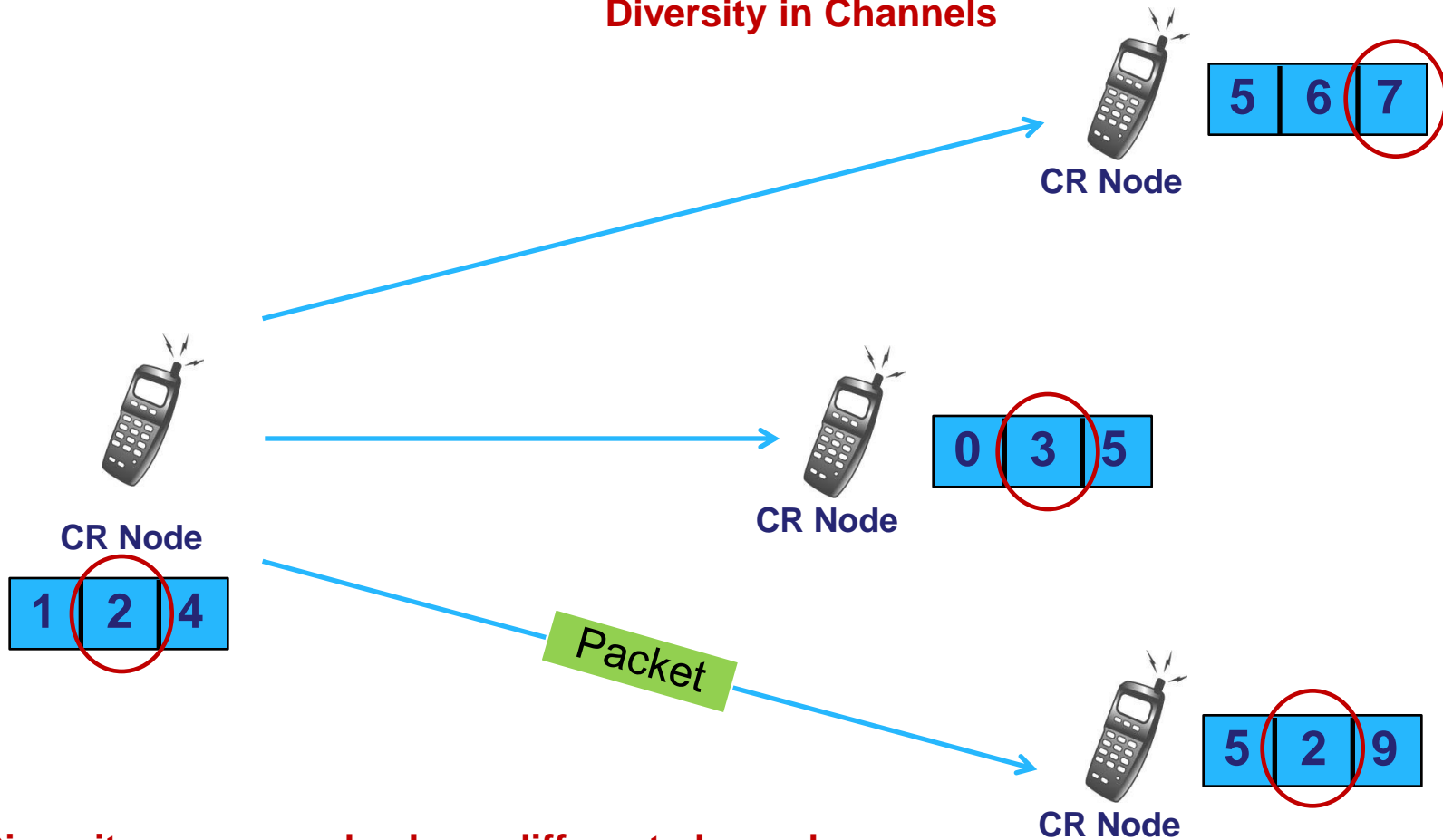
Why Data Dissemination is Challenging in Multi-Hop CRNs?

Multiple Channels



Why Data Dissemination is Challenging in Multi-Hop CRNs?

Diversity in Channels



Diversity means nodes have different channels

Diversity decrease the connectivity

First Step in Efficient Data Dissemination in CR Networks

- The first step in Efficient Data Dissemination is to select *Best Channels*
- Best Channel
 - Lowest PR activity
 - Higher number of CR Neighbors
- CR Nodes Objective
 - Protect the Primary Radio Nodes to Harmful Interference
 - Select best channel ensuring maximum connectivity and consequently, allowing largest data dissemination in the network

Related Work



Selective Broadcasting (SB) is the most related approach present in the literature

1ST CONTRIBUTION

**SURF: CHANNEL SELECTION
STRATEGY FOR DATA
DISSMINATION**

Channel Selection Strategy “SURF”

- Distributed
- Designed for Multi-hop Cognitive Radio Ad-Hoc Networks
- Ensures CR nodes to select best channels not only for transmission but also for overhearing
- Convey emergency alarms and alerts [1] or to deliver low priority data such as advertisement messages

[1] Mubashir Husain Rehmani, Aline Carneiro Viana, Hicham Khalife, and Serge Fdida, A Cognitive Radio Based Internet Access Framework for Disaster Response Network Deployment, In Proceedings of the 3rd International Workshop on Cognitive Radio and Advanced Spectrum Management (CogART'10), in conjunction with ISABEL 2010, Rome, Italy, 08-10 Nov 2010

Channel's Weight

- Channel's Weight is calculated as:

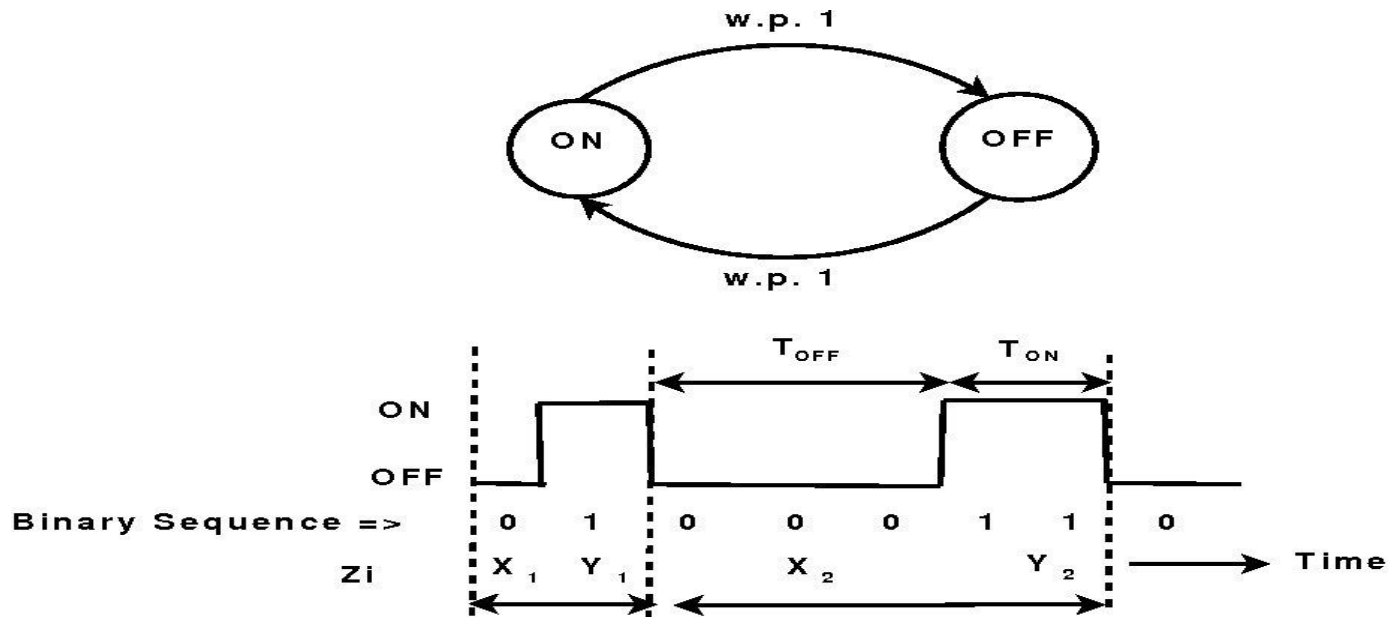
$$PW_{(i)} = PR_u^{(i)} \times CR_o^{(i)}$$

PR_u = Primary Radio Unoccupancy

CR_o = Cognitive Radio Occupancy

- To achieve two objectives:
 - To protect the ongoing PR activity by selecting the least occupied channel by PR nodes
 - To ensure maximum connectivity by selecting the channel that has higher number of CR neighbor nodes

Primary Radio Unoccupancy



Alternating ON/OFF Markov Renewal Process

Best channel: highest Probability being in OFF state $P_{OFF}(t)$

$$P_{OFF}(t) = [\lambda_X / (\lambda_X + \lambda_Y)] + [\lambda_Y / (\lambda_X + \lambda_X)] e^{-(\lambda_X + \lambda_X)t}$$

λ_X and λ_Y = Rate parameters of exponential distribution

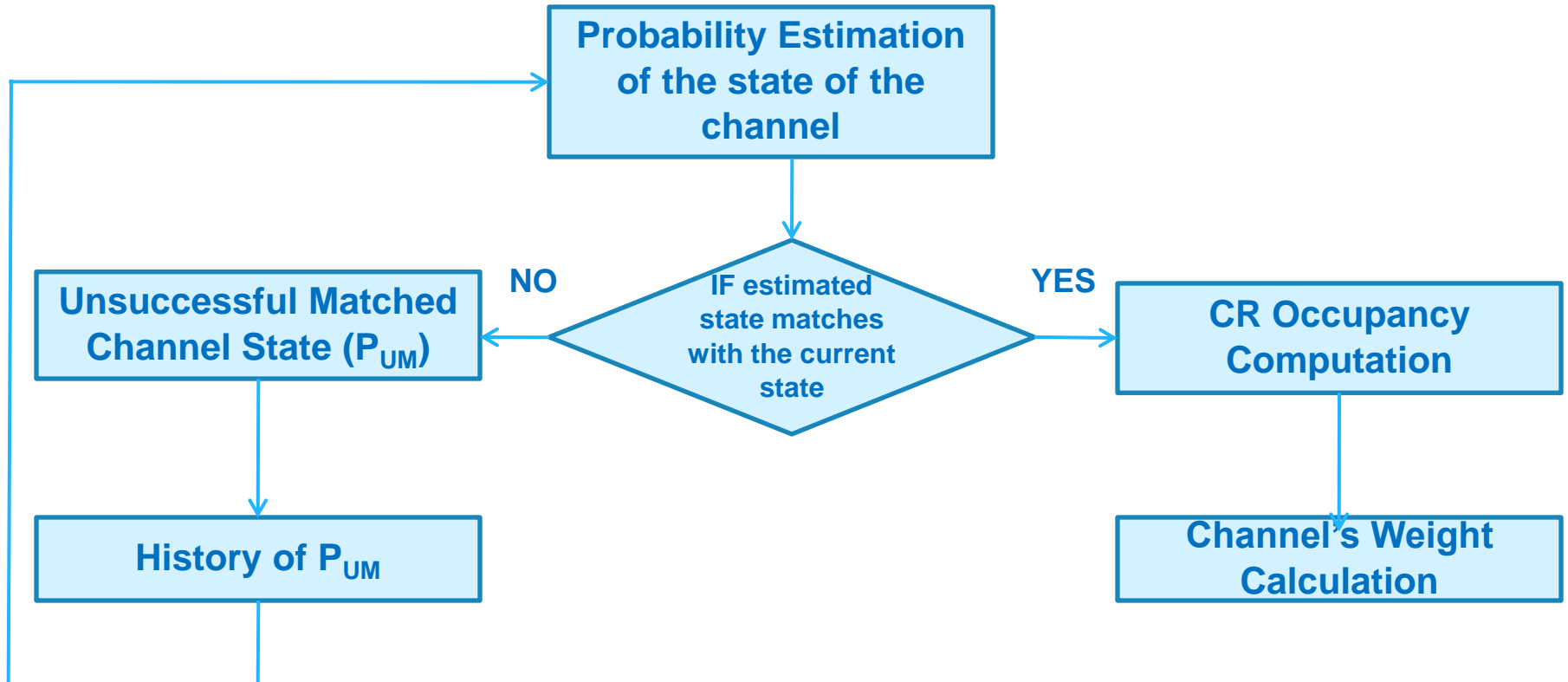
Probability estimation can be wrong !

Wrong Estimation of Channel Availability

P_{OFF} Estimation	Measured Channel State	Probability
ON	OFF	P_{FA}
OFF	ON	P_{MD}

- P_{FA} = Probability of False Alarm
 - Declared unoccupied channel as busy
 - Loose spectrum opportunity
- P_{MD} = Probability of Miss Detection
 - Declared busy channel as unoccupied
 - Harmful interference to PR nodes

Wrong Estimation of Channel Availability



How to Compute P_{MD} and P_{FA} ?

$$P_{MD} + P_{FA} = X_{nt}/N$$

- P_{MD} = Probability of Miss Detection
- P_{FA} = Probability of False Alarm
- X_{nt} = number of times the estimated channel state does not match with the actual channel state
- N = number of times the channel selection occurs

$$PR_u^{(i)} = P_{OFF}^*(t)^{(i)} = P_{OFF}^{(i)}(1 - P_{FA}^{(i)}) + P_{MD}^{(i)}(1 - P_{OFF}^{(i)})$$

- In perfect channel estimation, $P_{OFF}^* = P_{OFF}$

Cognitive Radio Occupancy

- Reflects the number of CR neighbors using the Channel
- Higher number of CR neighbors provides:
 - Good level of network connectivity
 - Consequently, increase the transmission coverage of CR nodes
- CR neighbors can be discovered by using:
 - With Common Control Channel (CCC) [1] or
 - Without Common Control Channel, such as [2]

$$CR_o = CR_n$$

where CR_n is the number of CR neighbors using channel

[1] S. Koukas Lazos and M. Krunz, "Spectrum opportunitybased control channel assignment in cognitive radio networks," in 6th IEEE SECON, Rome, Italy, 2226 June

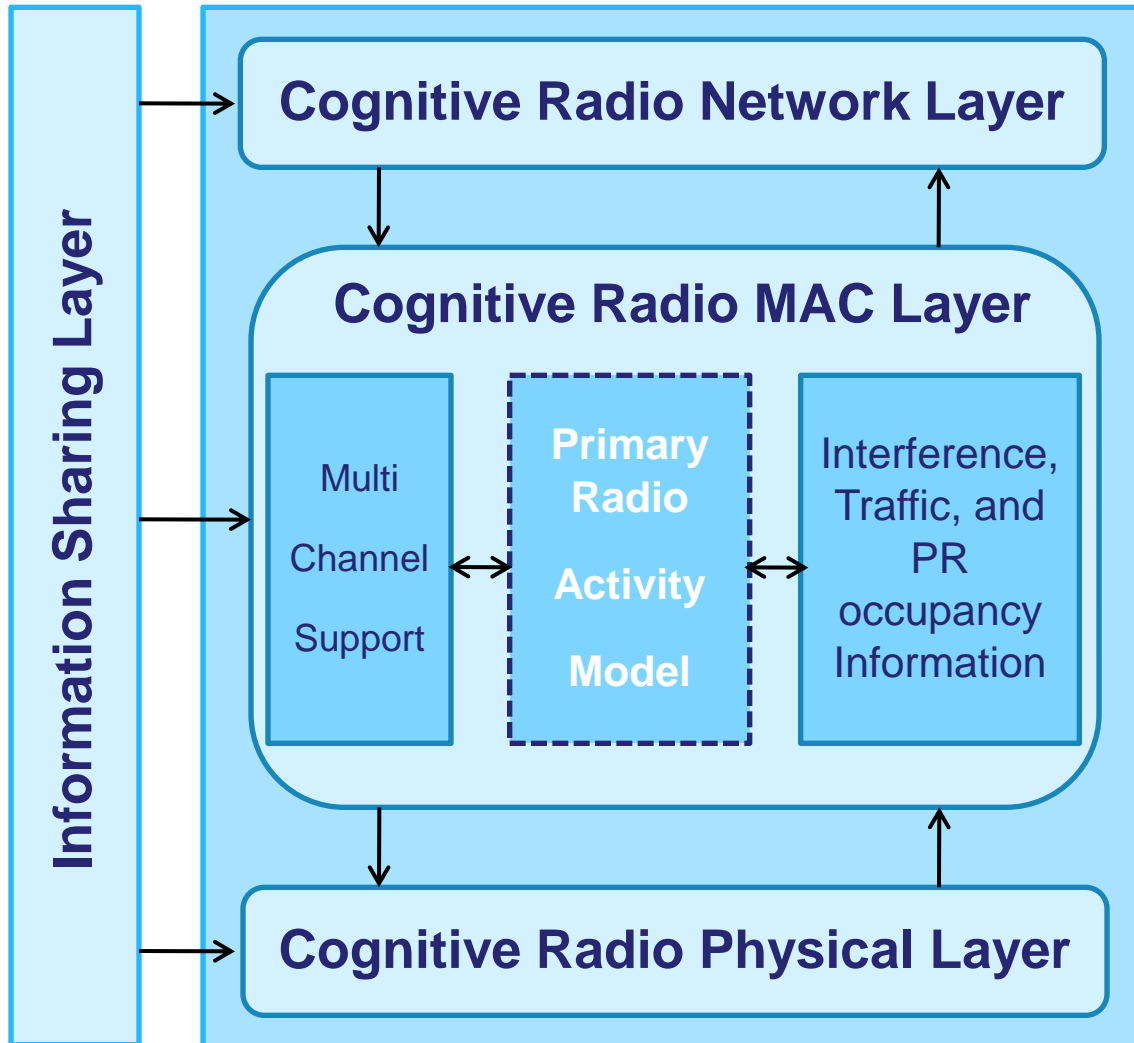
[2] C. Arachchige, S. Venkatesan, N. Mittal, An asynchronous neighbor discovery algorithm for cognitive radio networks, in: 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2008. DySPAN 2008.

Simulation Environment

- Network Simulator (NS-2), 1000 runs, 95% of confidence interval
- Total 1000 packets, each packet is sent by a randomly selected node
- Grid Size $a^2 = 700 \times 700 \text{ m}^2$
- Transmission Range $R = 250\text{m}$ and Number of CR nodes $N=100$
- TTL = 6, to disseminate the message in the whole network
- 2 Sets of Topologies for Ch=5 and Ch=10
 - Channels Ch=5 are assigned from the pool of 8, random assignment
 - Channels Ch=10 are assigned from the pool of 12, random assignment
 - If the pool is too large, network get disconnected, else no diversity is present
 - Average neighborhood density: 11.3 (Ch=5) and 20.1 (Ch=10)

Network Simulator NS-2

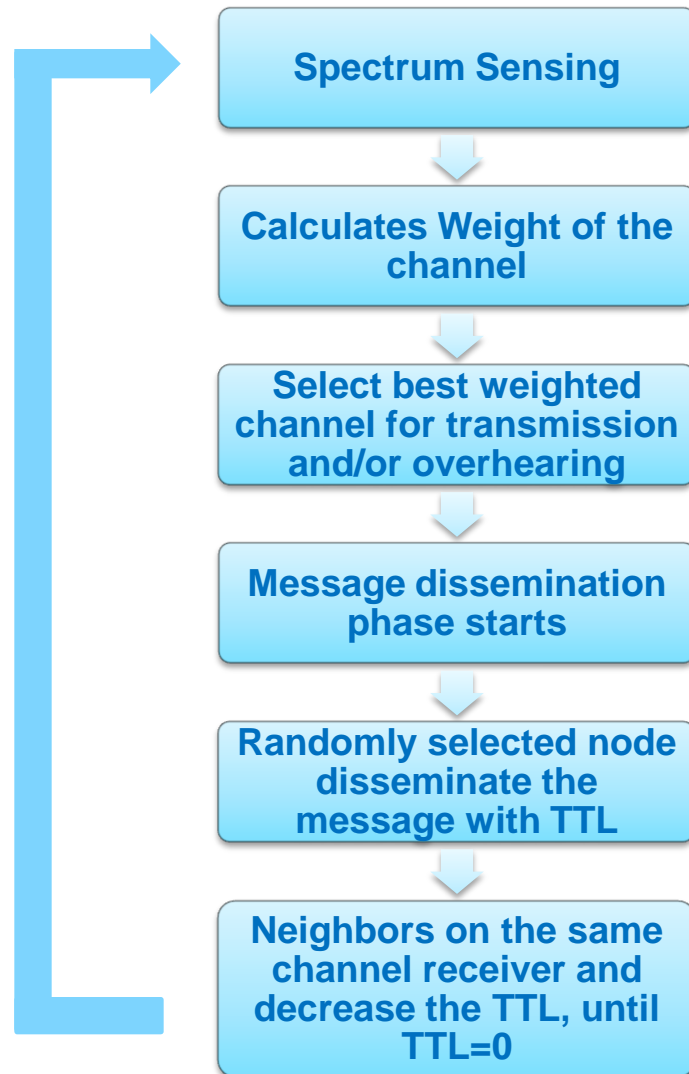
Modifications



- CRCN Patch NS-2
- PR Activity Model is added
- Simple MAC Protocol is added

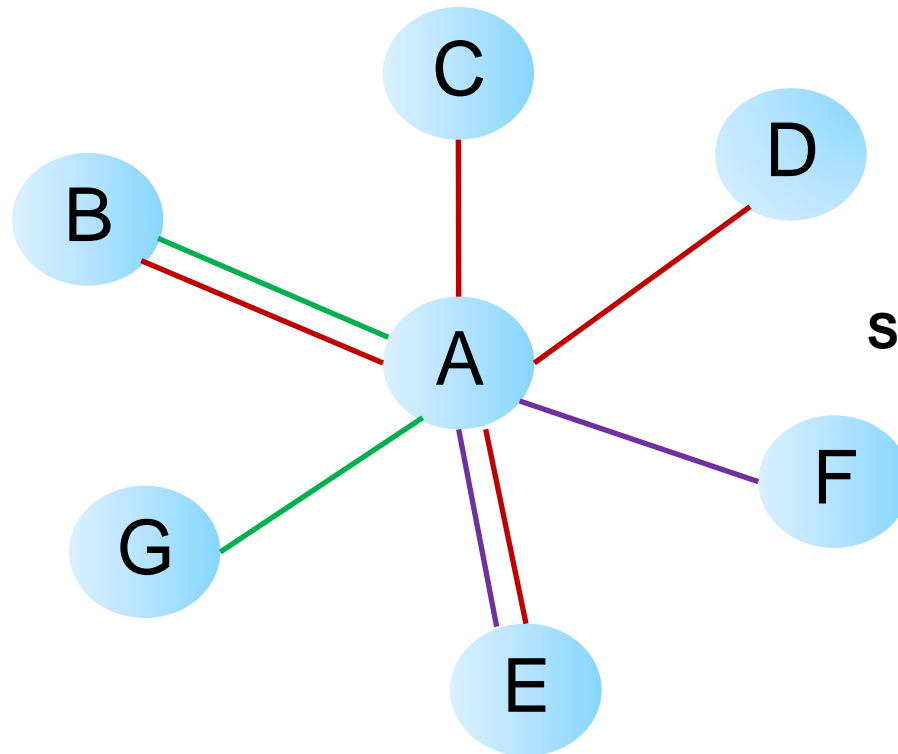
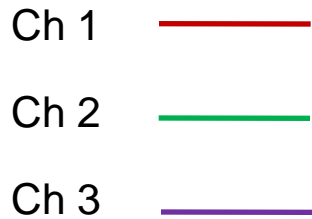
Code Available at: <http://www-npa.lip6.fr/~rehmani/NS2 Code.zip>

Strategy Followed by CR Nodes



Performance Evaluation

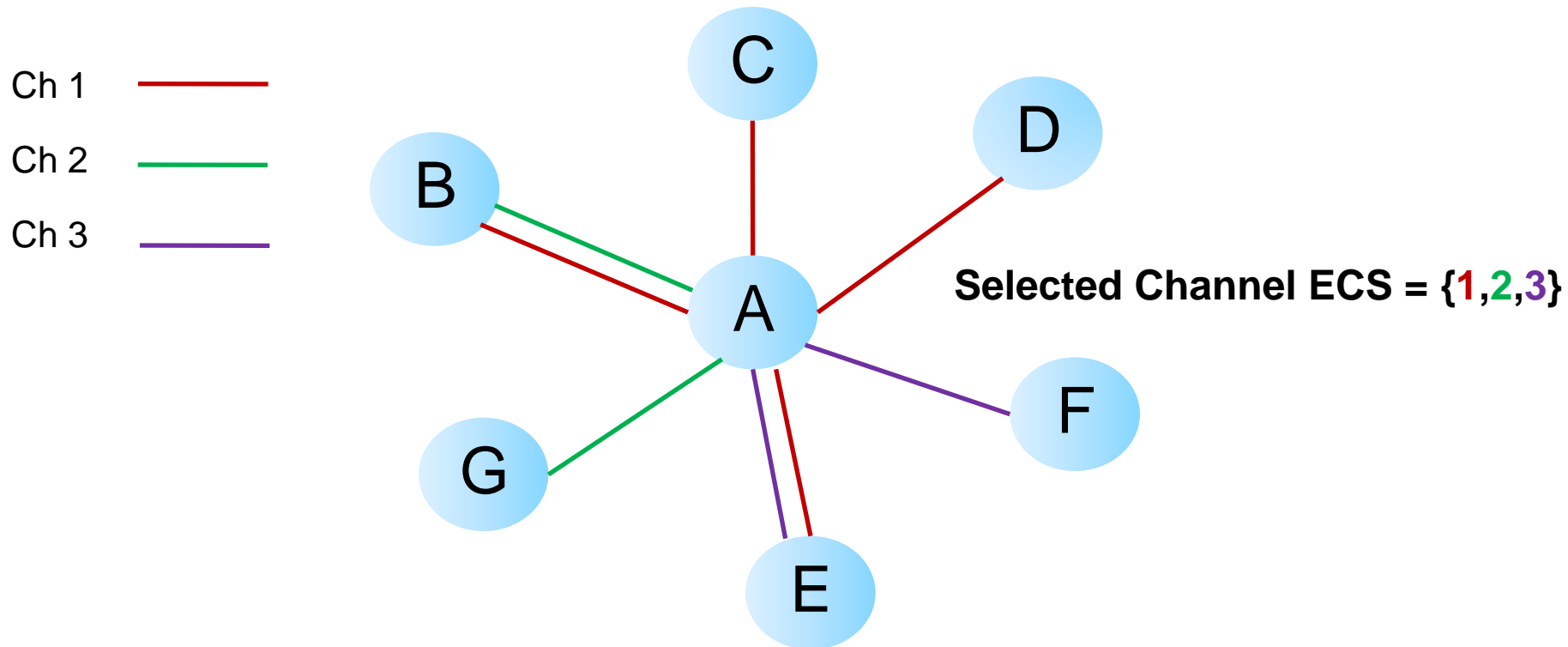
Random



Selected Channel = 2

Performance Evaluation

Selective Broadcasting (SB) [1]

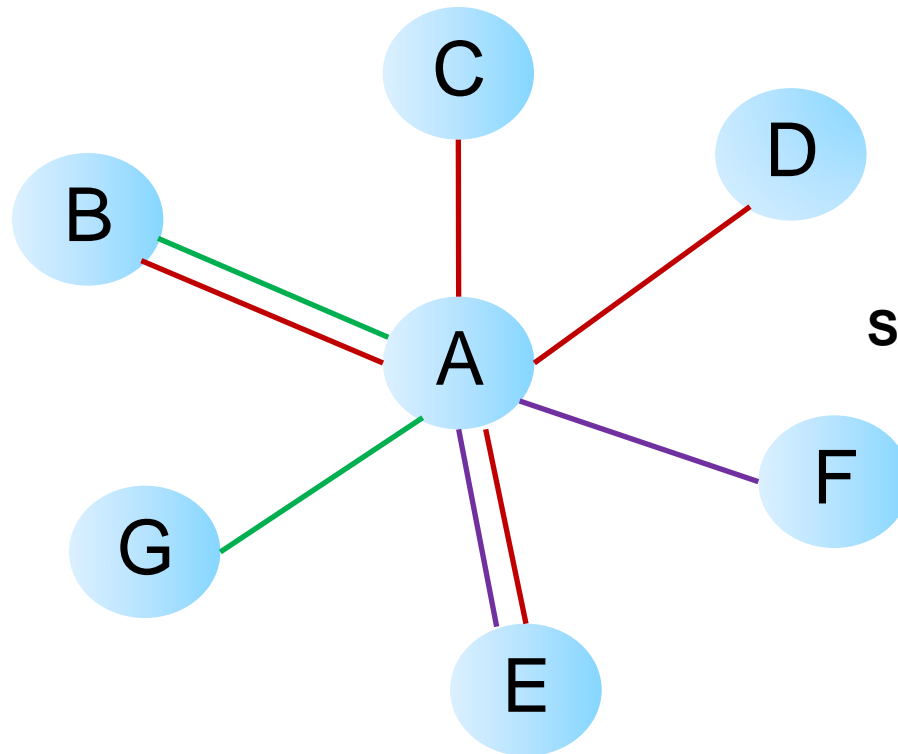
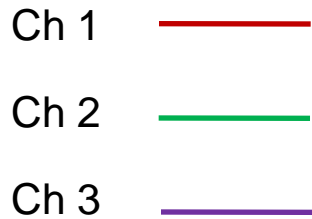


Essential Channel Set (ECS) = Channel set that covers all the geographic neighbors

[1] Y. R. Kondareddy, and P. Agrawal, "Selective Broadcasting in Multi-Hop Cognitive Radio Networks", IEEE Sarnoff Symposium, pp. 15, 2830 April 2008.

Performance Evaluation

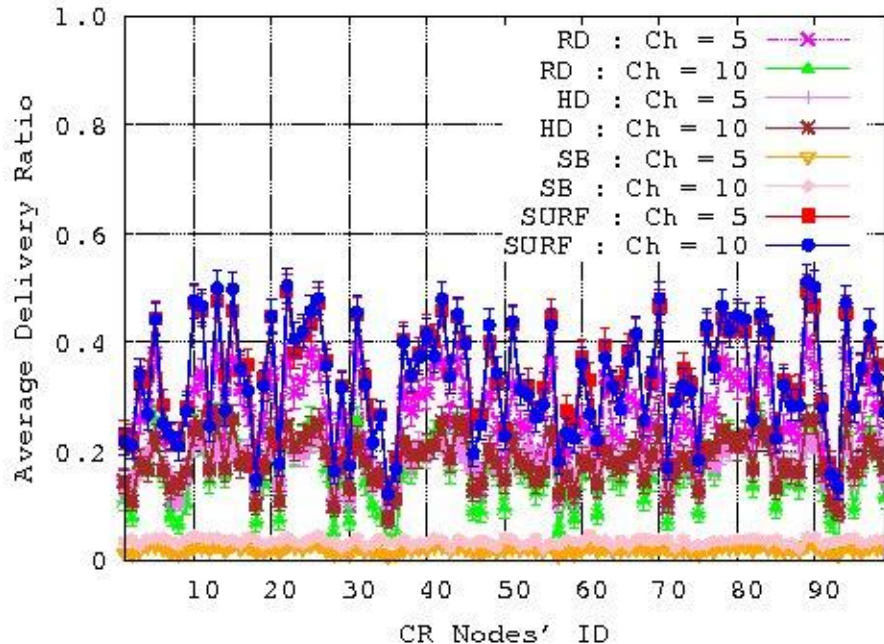
Highest Degree



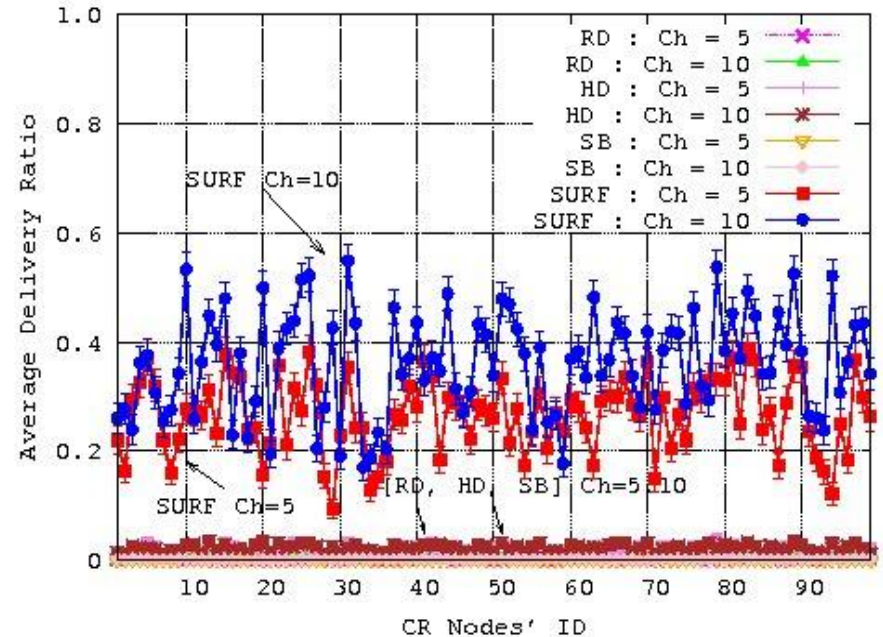
Selected Channel = 1

Data Dissemination Robustness

PR Activity is *not* Present



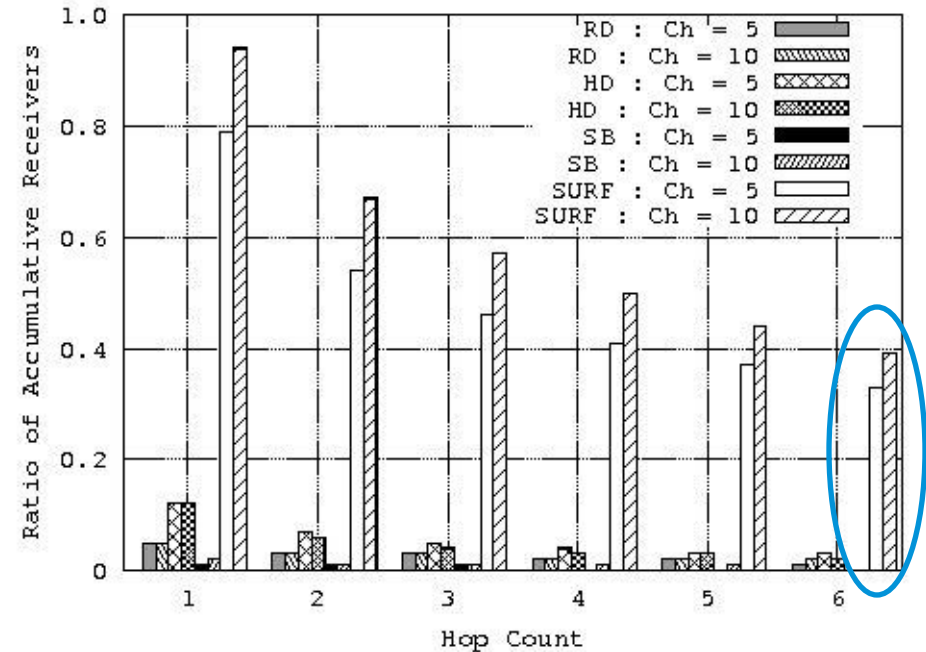
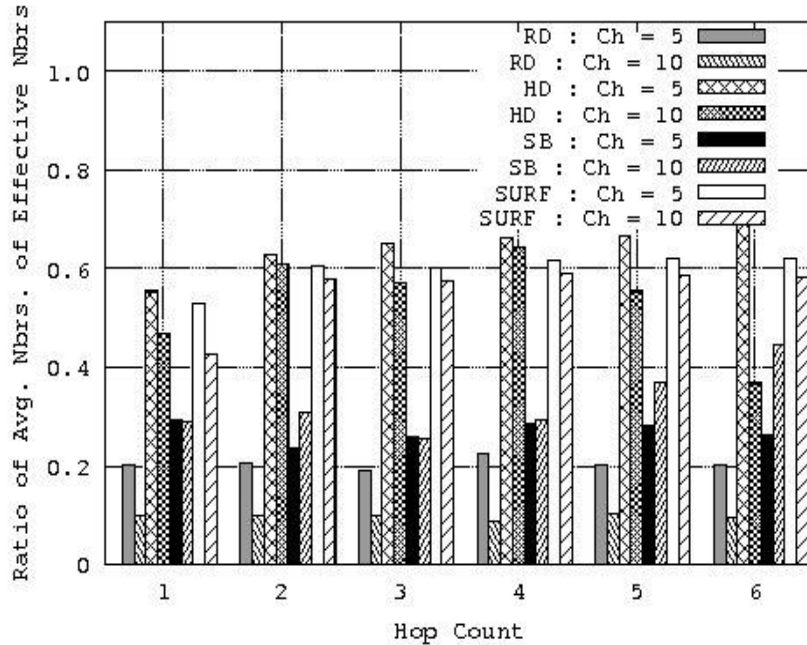
PR Activity is Present



SURF guarantees the delivery of approx. 40% of messages

Avg. Delivery Ratio: It is the ratio of packet received by a particular CR node over total packets sent in the network.

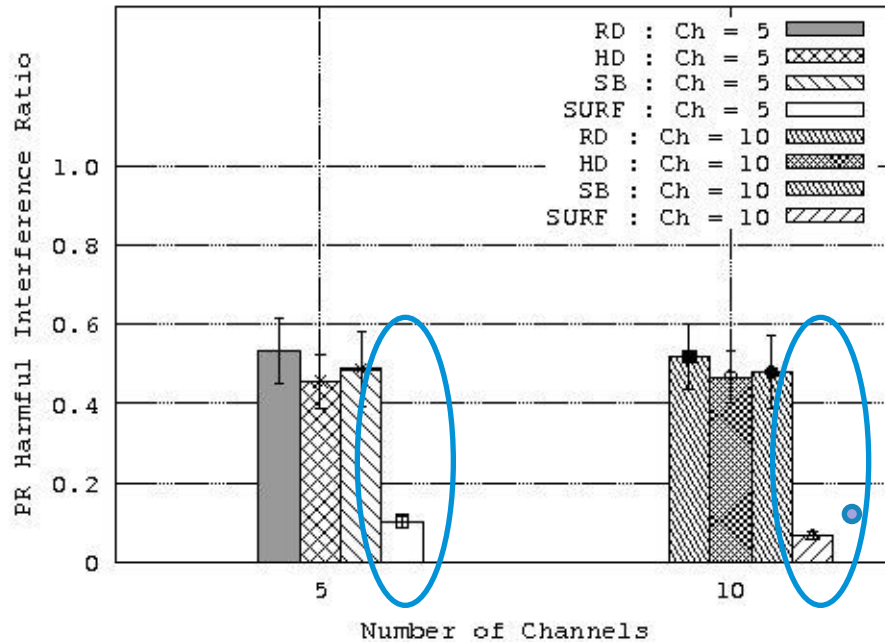
Data Dissemination Robustness



Effective neighbors are the number of neighbors that select the same channel for overhearing as the sender node used for transmission

Avg. Accumulative Receivers: It is the average ratio of accumulative CR receivers per hop

Protection to PR Nodes



SURF
Protects the
PR Nodes

Harmful Interference Ratio (HIR): It is the ratio of the total number of times the channel is occupied by PR node after the channel selection decision over total number of times the channel selection decision occurs

1st Contribution: Conclusion

- A channel selection strategy, SURF, is proposed for data dissemination in multi-hop cognitive radio network
 - Protect the primary radio node to cause harmful interference during CR transmissions
 - Create a connected cognitive radio network with high probability for largest data dissemination
- Enhanced NS-2 to include PR activity model

2ND CONTRIBUTION

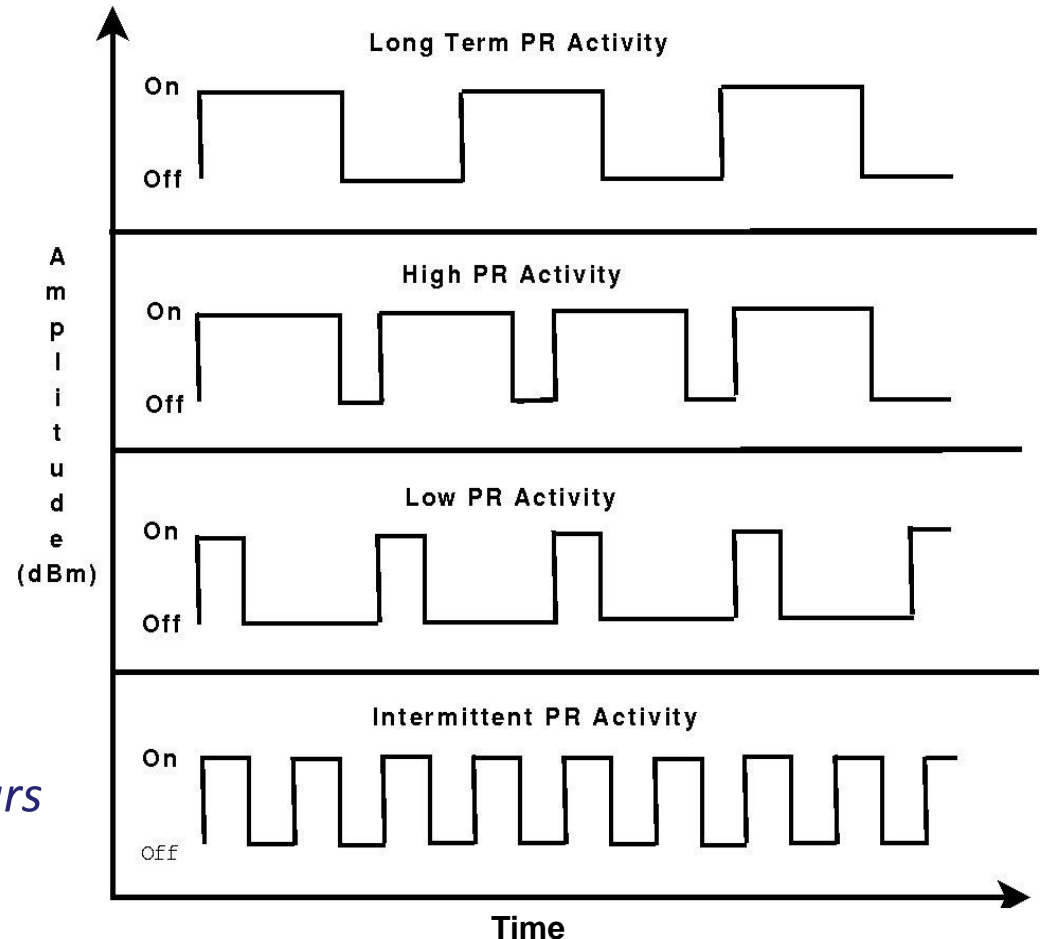
IMPACT OF PR NODES ACTIVITY PATTERN ON CHANNEL SELECTION STRATEGIES

Motivation Regarding PR Activity Analysis

- The performance of CR network is highly dependent upon the PR nodes activity pattern
- Related works did not consider:
 - The impact of different PR nodes activity pattern on different channel selection strategies as well as on data dissemination.
- We study and analyze:
 - The impact of different PR nodes activity pattern
 - Four channel selection strategies and three performance metrics

PR Nodes Activity Pattern

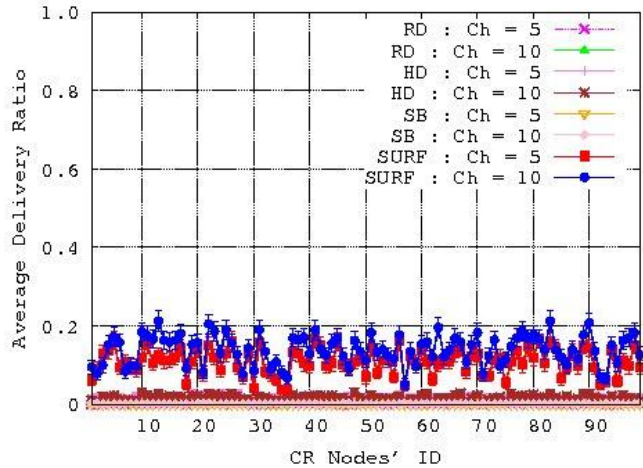
- *Long Term PR Activity:*
 - *Long ON and Long OFF*
 - *Free call packages*
- *High PR Activity:*
 - *Long ON and Short OFF*
 - *Rush hours, urban areas*
- *Low PR Activity:*
 - *Short ON and Long OFF*
 - *Remote areas, less peak hours*
- *Intermittent PR Activity:*
 - *Short ON and Short OFF*
 - *Bus stations, railway stations*



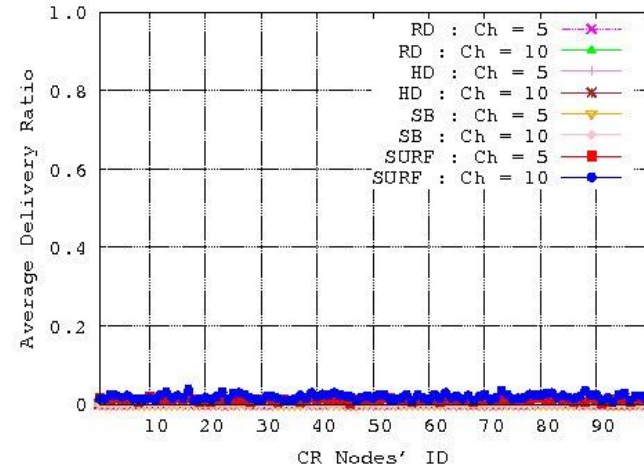
Simulation Environment

- Network Simulator (NS-2)
- Comparison of SURF, RD, HD, and SB
- Results are generated for 1000 runs with 95% of confidence interval
- Total 1000 packets were sent, where each packet is sent by a randomly selected node after 1 second
- Grid Size $a^2 = 700 \times 700 \text{ m}^2$
- Transmission Range $R = 250\text{m}$ and Number of CR nodes $N=100$
- TTL=6 is introduced to disseminate the message

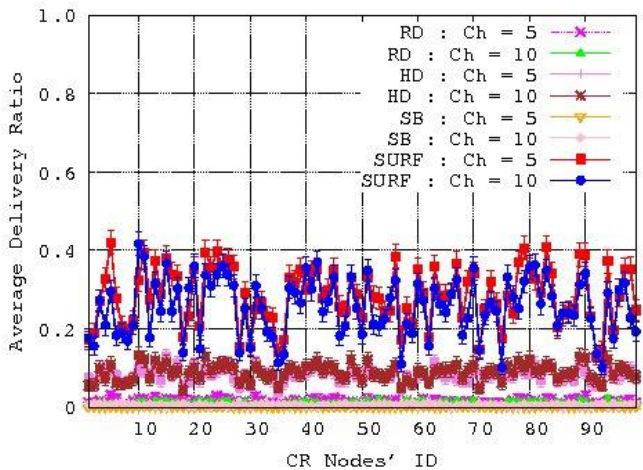
Average Delivery Ratio



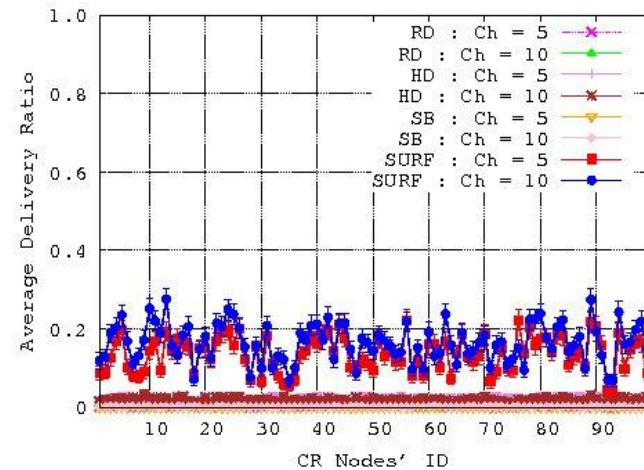
Long Term PR Activity



High PR Activity

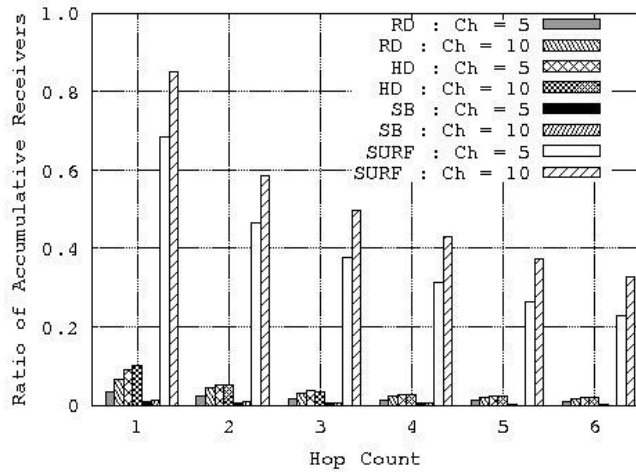


Low PR Activity

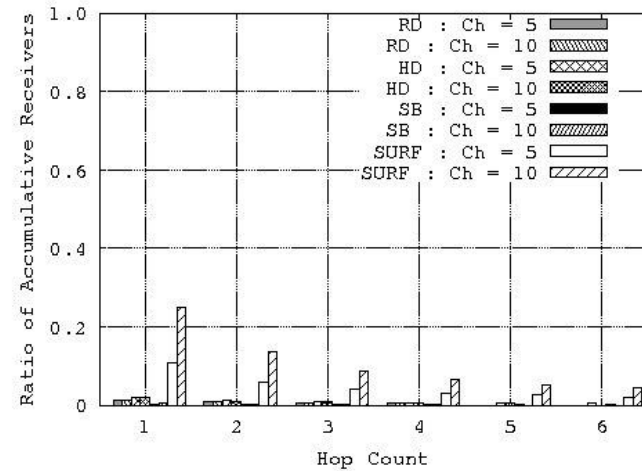


Intermittent PR Activity

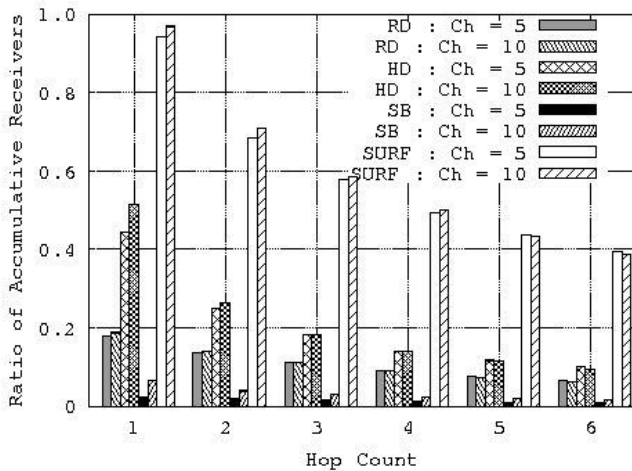
Hop Count and Accumulative Receivers



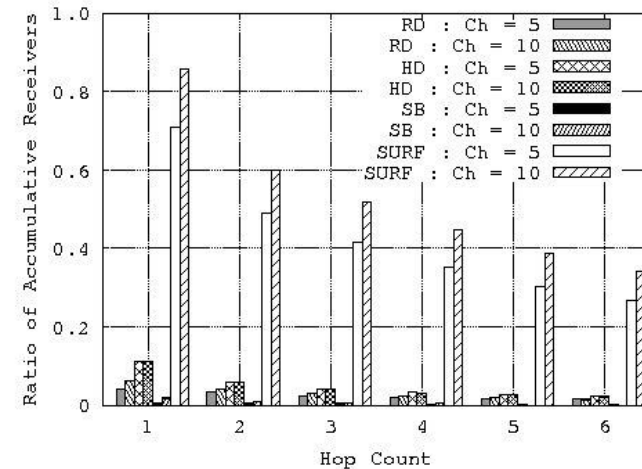
Long Term PR Activity



High PR Activity

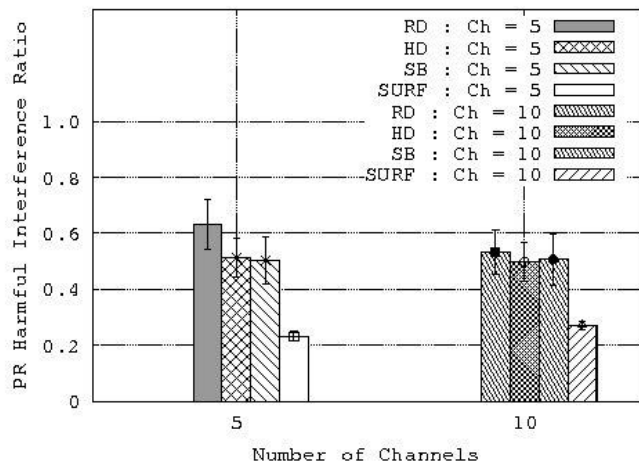


Low PR Activity

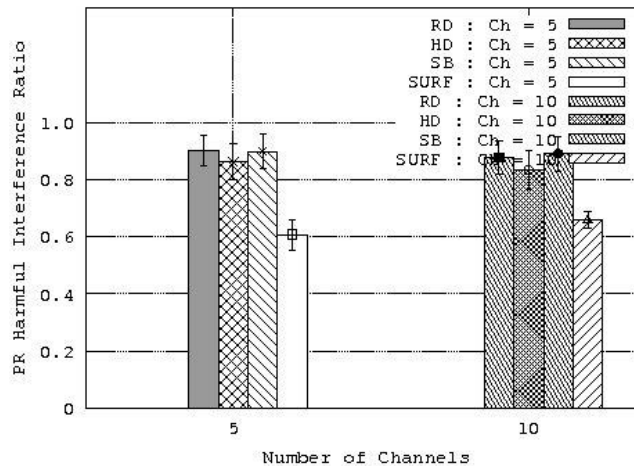


Intermittent PR Activity

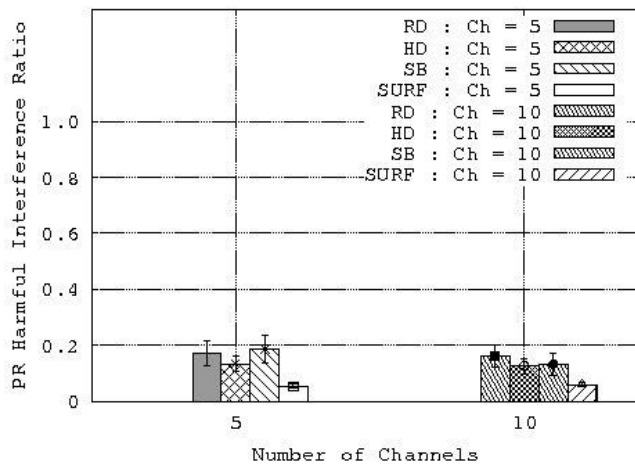
PR Harmful Interference Ratio



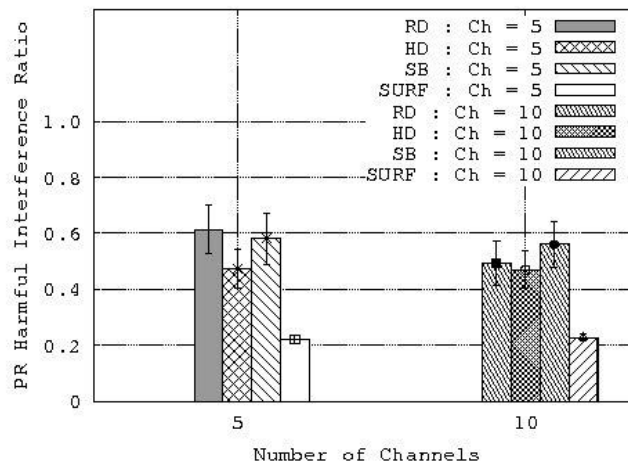
Long Term PR Activity



High PR Activity



Low PR Activity



Intermittent PR Activity

2nd Contribution: Main Conclusions

- Low PR activity:
 - Every solution offers acceptable gain, clever solution is not worth
- High PR activity:
 - All solutions performed bad, no real opportunity for transmission
- Intermittent PR Activity:
 - Clever solutions need to operate , SURF gives the best results
 - Enhancements regarding SURF “History Based Metrics”
 - How often the channel is free?
 - SURF may keep history of channel ON/OFF states
 - How long channel stay in OFF state?
 - SURF may compute the duration of OFF state in the considered time

3RD CONTRIBUTION

APPLICABILITY OF SURF

AN INTERNET ACCESS FRAMEWORK FOR FUTURE COGNITIVE RADIO NETWORKS

Telecommunication Infrastructure Destruction through Natural Disasters



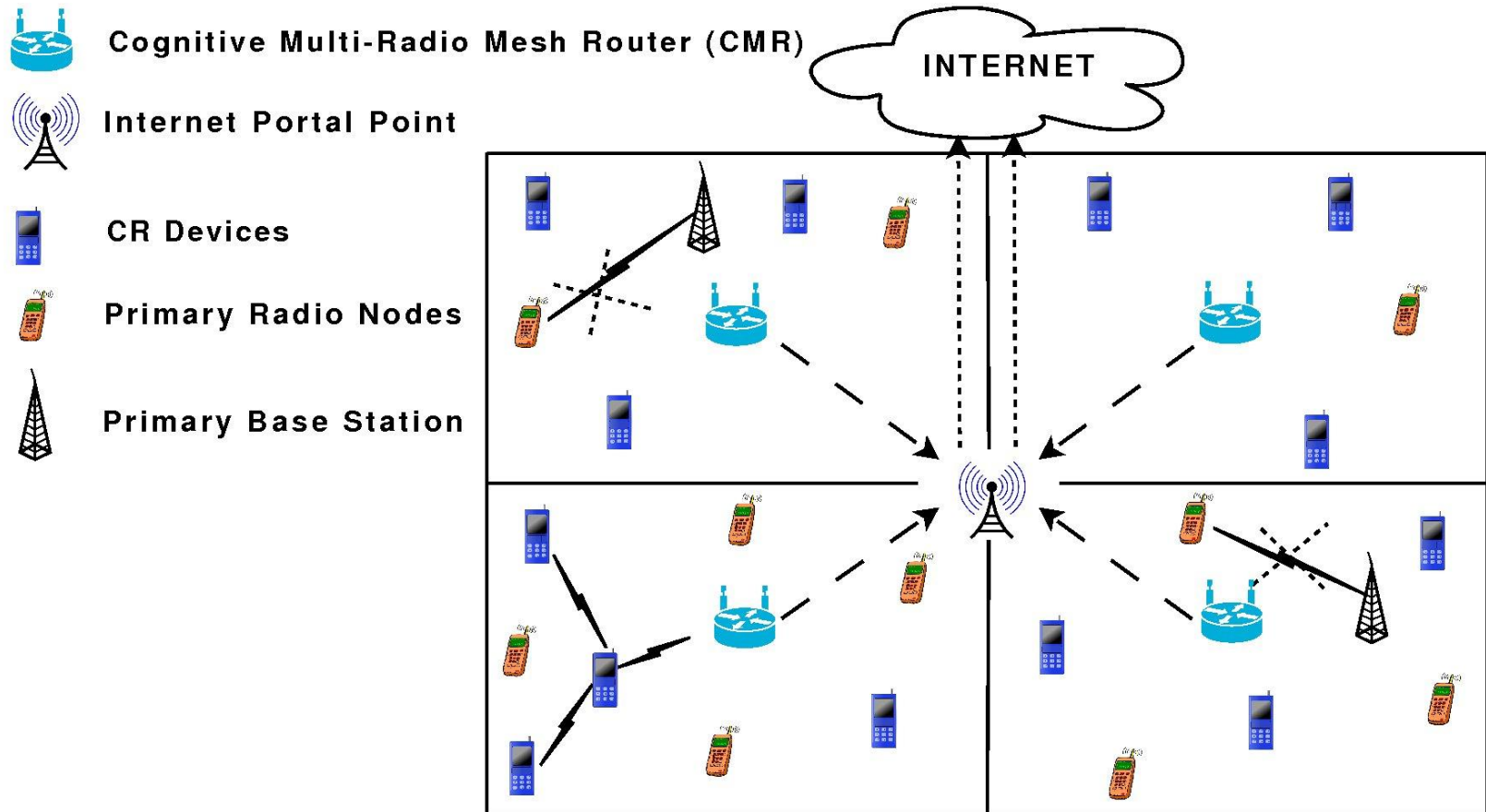
Restoration of Partially Destroyed Telecommunication Networks

- Instantaneous deployment of core telecommunication infrastructure is not feasible
 - Due to planning and cost
 - E.g. base stations in the case of cellular networks
- Quick need to help rescue team members and NGOs
 - To facilitate organized help
 - Rehabilitation works

Need for Disaster Response Networks

To provide connectivity and Internet access

An Internet Access Framework for Future Cognitive Radio Networks



Functionality of Framework Components

- Cognitive Radio (CR) Devices:
 - Access any cognitive multi-radio mesh router
 - Mobile
 - Single Hop and Multi-Hop
- Cognitive Multi-Radio Mesh Routers (CMRs):
 - Intercommunicate between CR devices and internet portal point
 - Data transfer
 - Connectivity to Global Internet
- Internet Portal Point
 - Gateways to Internet
 - Powerful communication medium

Restoration of Partially Destroyed Networks to Global Internet



CR devices



Non-CR devices



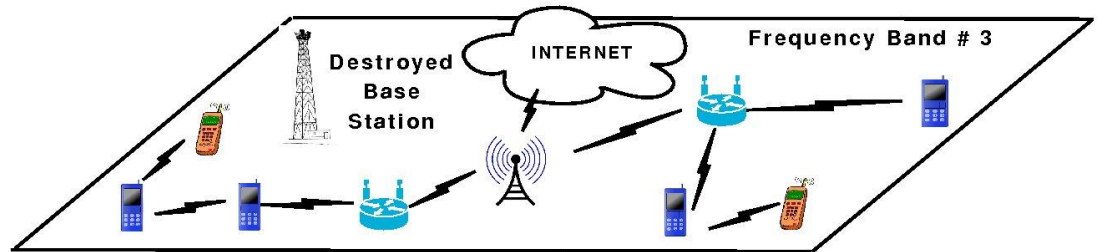
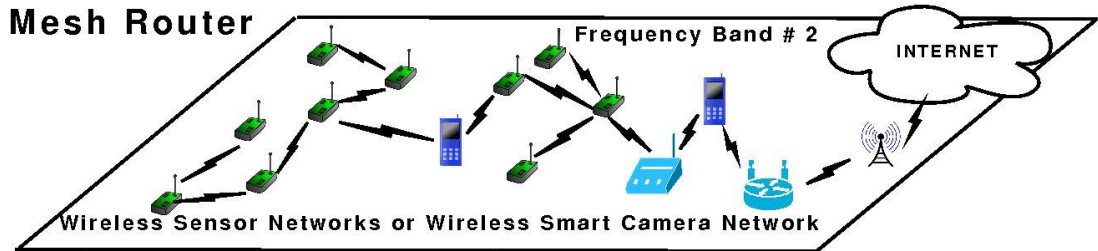
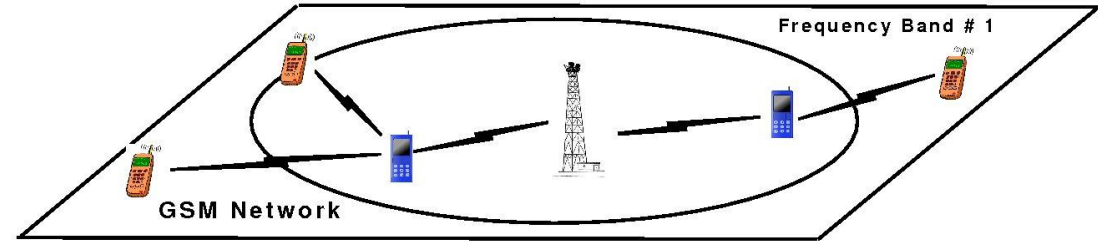
Internet Portal Point



Cognitive Multi-Radio Mesh Router



GSM Base Station



Deployment and Connectivity: Issues and Challenges

- Network Deployment and Connectivity:
 - Centralized or Ad-Hoc
 - Connectivity

Without any intelligent channel selection strategy, there will be contention and collisions, which results in packet losses

- Infrastructure Discovery:
 - Wi-Fi access points
 - GSM base stations, etc.
- Internetwork Coordination:
 - Communication of CR devices with distinct network entities

How SURF could be used in the Framework?

- Without any intelligent channel selection strategy
 - Concentration of all the CR devices over a particular channel
 - Lead to contention and collisions problem
 - reduce the connectivity
- SURF could be used by CR devices to:
 - Forward data to cognitive multi-radio mesh router
 - Among CR devices in multi-hop scenarios

CONCLUSION AND FUTURE WORK

Conclusion

- We presented SURF, a channel selection strategy for data dissemination in multi-hop cognitive radio networks
 - PR activity model is included in NS-2
- We studied the impact of primary radio nodes activity on four channel selection strategies
- We discussed the applicability and feasibility of SURF

Future Work

- Channels activity model of a PR network
 - PR activity models depend upon the underlying PR network
 - How to develop adaptive strategies that could be able to detect the PR activity
- Exploitation of Real Traces of PR activity
 - Exploit PR activity traces to minimize the gap between theory and practice
- Improvements in SURF considering PR activities' study
 - How often the channel is free?
 - How long channels stay in OFF state?

THANKS
QUESTIONS?