Multiconstrained QoS Aware MAC Protocol for Cluster-based Cognitive Radio Sensor Networks

B. Sc. 4th year (Hons.) project presentation

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Overview

- Cognitive Radio Technology
- Cognitive Radio Sensor Network
- Advantages
- Research Challenges
- Project Contribution
- State-of-the-Art Models
- Network Model & Assumptions
- Proposed MQ-MAC Protocol
- Performance Evaluation
- Conclusion
- References

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Cognitive Radio Technology

- Cognitive Radio is a form of wireless communication in which a transceiver intelligently detect which communication channels are in use and which are not and instantly move into vacant channels avoiding the occupied one.
- This **optimizes the usage of spectrum** while **minimizes interference** with others.

Cognitive Radio Technology

Dynamic Spectrum Access(DSA) is all about Cognitive Radio.

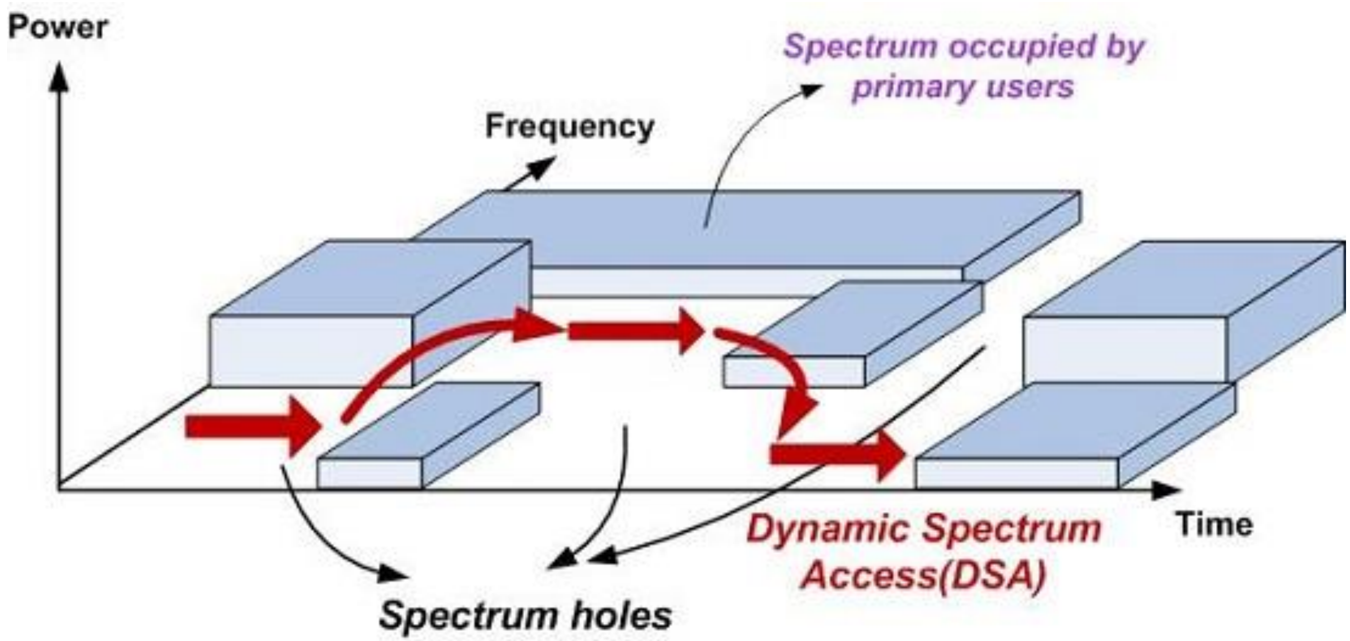
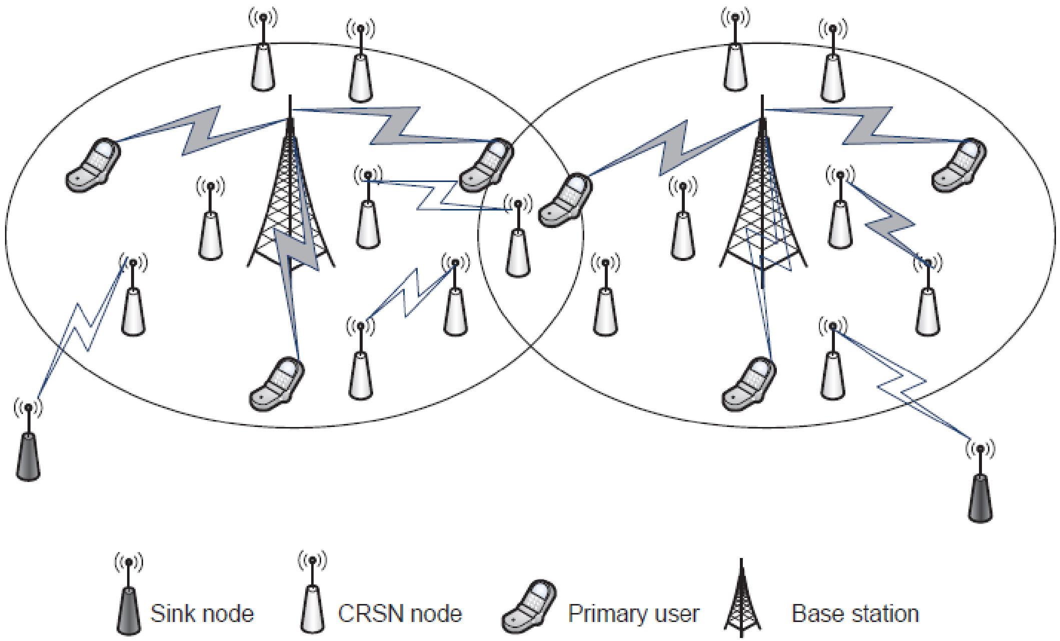


Fig. : Spectrum holes & dynamic spectrum access(DSA)

Advantages of CR

- Efficient Utilization of Unused Licensed Band.
- Reduction of Spectrum Shortage Problem

Cognitive Radio Sensor Network



Basically a WSN integrated with CR capability is known as **CRSN.**

-Which is a new era of wireless communication

e.g. In Warfield monitoring, medical center, environmental monitoring, Temperature monitoring etc. can be done more efficiently with CRSN.

Research Challenges

Research Challenges

- Changing Spectrum Environment & spectrum behavior
- Selecting Best available channel set for channel sensing and selection.
- Protecting the transmission of primary users (PUs)
- Ensuring reliability during data transmission

Project Contribution

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Project Contributions

- A multiconstrained QoS aware **MAC protocol (MQ-MAC)** for cluster-based CRSN
- **Traffic prioritization** for heterogeneous data
- QoS aware dynamic **superframe structure**
- An intelligent **fusion operation** over the cooperative sensing result
- A new **GTS allocation algorithm**
- A new **dynamic data channel assignment algorithm**
- A new **backup channel assignment algorithm**
- Finally, The performance evaluations in NS-3 [23] show that the proposed MQ-MAC achieves better performances.

Recent Works

State-of-the-art Solutions

The most recent works on CRSN:

KoN-MAC[20]-

- Basically optimizes the channel selection and sensing mechanism by selecting best K(<=N) channels from N available channels for sensing.

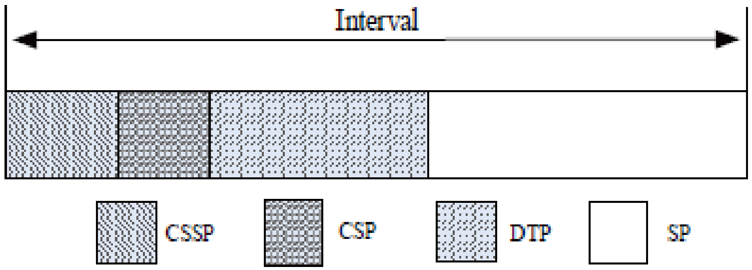

Fig.: Superframe structure of KoN-MAC

Limitation – QoS not maintained, No data prioritization, Packet lifetime not considered during scheduling, High packet loss ratio.

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Comparison

Metrics	IEEE 802.15.4 [32]	KoN-MAC [20]	MQ-MAC
Traffic Prioritization	No	No	Yes
Ontime Reachability	Low	Medium	Very high
Energy Efficiency	No	Yes	Yes
SU Blocking Rate	NA	Medium	Low

Table: Comparison between different state-of-the-art protocols with our protocol

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CRSN Network Model

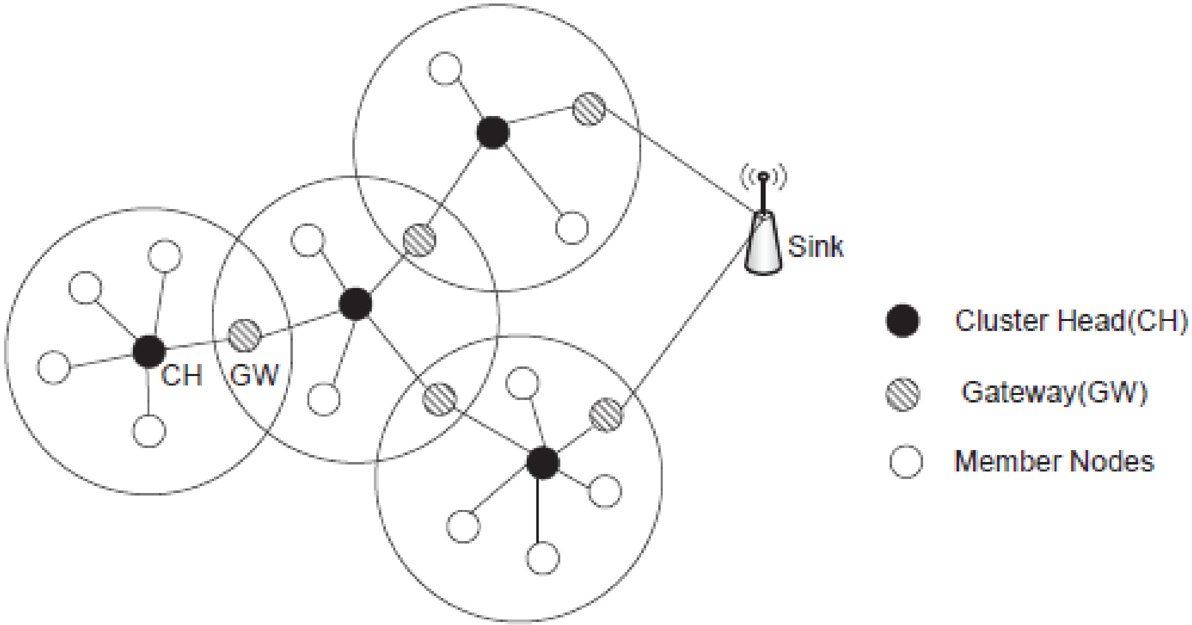

Fig. : The network model for CRSN

Network Model & Assumptions

- A Cluster based network.
- Cluster formation is done using LEACH[2] protocol.
- A Multihop network.
- Multichannel access is considered.

Traffic Classification

Traffic Class	Traffic Class Value (T_c)
Real time Reliable(RR)	0
Real time non-Reliable(RnR)	1
Non-Real time Reliable(nRR)	2
Best Effort(BE)	3

- 0: Both delay and reliability-constrained packets
- 1: Delay constrained but not reliability constrained packets
- 2: Reliability constrained but not delay constrained packets
- 3: neither delay constrained nor reliability constrained, normal packets

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Proposed MQ-MAC Protocol

MQ-MAC Protocol Design

- Data node Prioritization.
- A mechanism for selecting best channels for best possible nodes.
- Assignment of GTS for prioritized data for ensuring better QoS.
- Channel & backup channel assignment for DTP.
- Backup channel switching mechanism.

Subset Selection and Channel Sensing Mechanism

- a subset of K from N number of channels will be selected for channel sensing and thus reducing the energy consumption.

- Channel sensing is done on these K channels(called the polled-channel set, S_K) to find the best available set of channels C_b. ($|C_b| \leq K$).

- This is the main contribution of KoN-MAC protocol and here we begin our work.

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States and Weights of channels

States	Description	Channel Weight
Idle	SU finds the channel available	W_{idle}
Busy	SU finds PU using the channel	W_{busy}
Active	SU uses the channel to transmit data successfully	W_{act}
Collision	PU or other SU appears while SU is transmitting data	W_{col}

Will be increased by W_{idle} if sensed Idle

Will be decreased by W_{busy} if sensed Busy

Will be increased by W_{active} if Active

Will be decreased by $W_{collision}$ if Collision

Here, There will be an initial weight for each channel W_{in} and always the weight W will be in the following range, $0 \leq W \leq 1$

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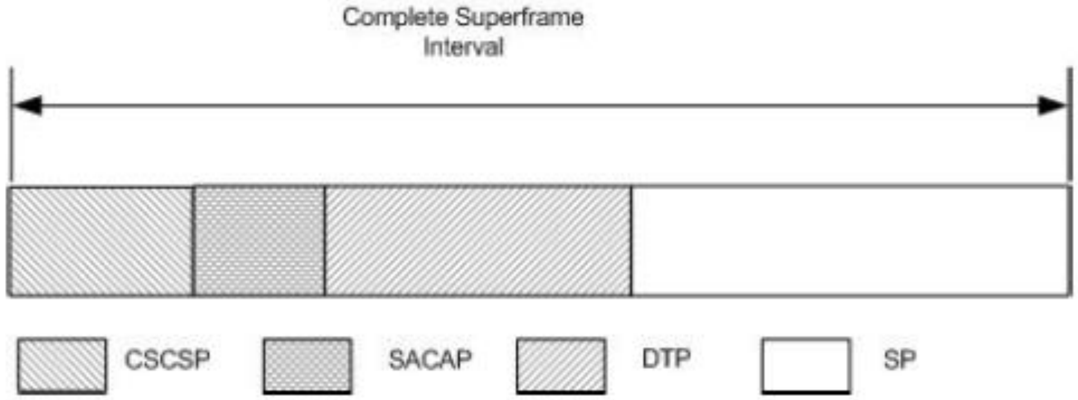
Super frame Structure



- Cooperative Sensing & Channel Selection Phase(CSCSP)
- Slot Allocation & Channel Assigning Phase (SACAP)
- Data Transmission Phase (DTP)
- Sleeping Phase (SP)

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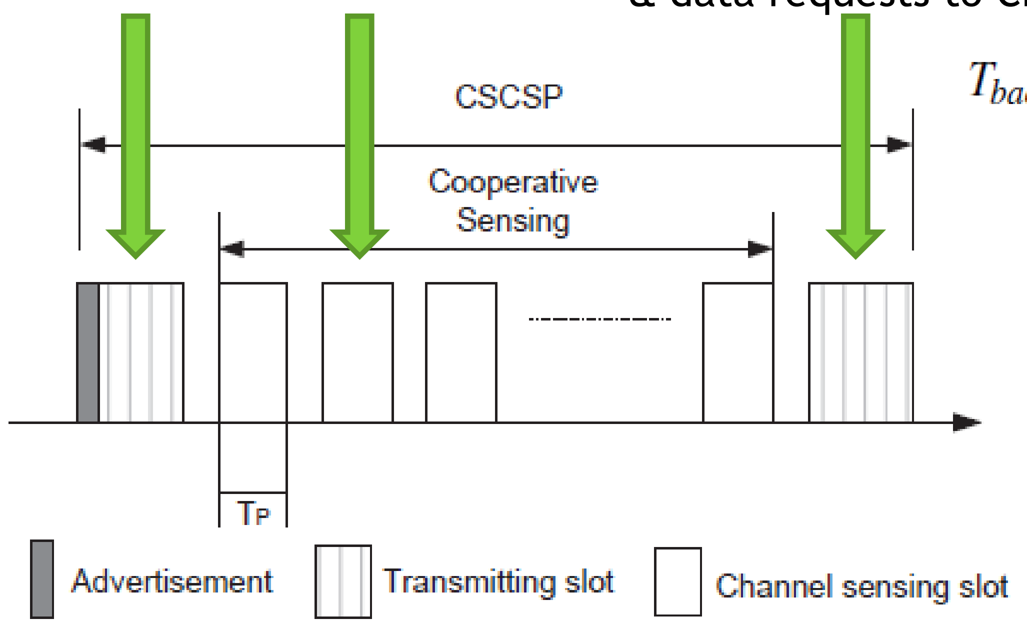
Cooperative Sensing and Channel Selection Phase (CSCSP)

CH Sends SK to all the nodes

CH with all nodes sense the K chanels

Nodes send back their sensed results & data requests to CH using,

$$T_{back-off} = [0, 2^{T_C} - 1]$$



Slot Allocation and Channel Assignment Phase (SACAP)

- GTS Slot Allocation algorithm
- Data Channel Assignment algorithm
- Backup Channel Assignment algorithm
- Single slot Channel Assignment Algorithm
- Multi slot Channel Assignment Algorithm

GTS Slot Allocation

Algorithm 1 GTS allocation algorithm

INPUT: A_G, the set of GTS allocation request received during CSCSP **OUTPUT:** A_s the set of allocated slot for all requests

while A_G is not empty **do**
  if request is from RR **then**
    insert request in RR_{req}
    remove request from A_G
  else
    if request is from RnR **then**
      insert request in RnR_{req}
      remove request from A_G
    else
      if request is from nRR **then**
        insert request in nRR_{req}
        remove request from A_G
      end if
    end if
  end if
end while
Sort RR_{req}, RnR_{req} and nRR_{req} according to the increasing order of remaining packet lifetime
Merge RR_{req}, RnR_{req} and nRR_{req} into A_s
i=0
for Each element of A_s **do**
  Allocate i^{th} available GTS to A_s[i]
end for

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Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1	Nid	1	Nid	1
Tc	RR	Tc	RR	Tc	RR
Lt	1233	Lt	1233	Lt	1233

Nid	1	Nid	1
Tc	RR	Tc	RR
Lt	1233	Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1	Nid	1
Tc	RR	Tc	RR
Lt	1233	Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1	Nid	1
Tc	RR	Tc	RR
Lt	1233	Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1
Tc	RR
Lt	1233

Nid	1	Nid	1	Nid	1
Tc	RR	Tc	RR	Tc	RR
Lt	1233	Lt	1233	Lt	1233

Nid	1	Nid	1
Tc	RR	Tc	RR
Lt	1233	Lt	1233

Nid	1	Nid	1
Tc	RR	Tc	RR
Lt	1233	Lt	1233

Nid	1	Nid	1
Tc	RR	Tc	RR
Lt	1233	Lt	1233

Dynamic Channel Assignment

Let, C_b is the set of best available channels

we will calculate the mean and standard deviation of the channel weights of C_b as :

$$\mu = \frac{\sum_{i=1}^{n} WT_i}{n}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (WT_i - \mu)^2}{n}}$$

CASE 1: $\mu > T_{up}$ AND $\sigma \leq \sigma_{max}$

Channels with high probability of being free, uniformed.

CASE 2: $\mu \leq T_{up}$ AND $\sigma \leq \sigma_{max}$

Channels with moderate probability of being free and are almost same in nature.

CASE 3: $\mu \leq T_{up}$ AND $\sigma > \sigma_{max}$

If the channel weights are not uniformed and contain both high and medium weights.

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Dynamic Channel Assignment Approach

Algorithm 2 Dynamic channel assignment approach

1. calculate μ_{wt} using Eq. 3.4
2. calcualte σ_{wt} using Eq. 3.5
3. **if** CASE 1 **then**
4.   put all the channels in BL
5. **else**
6.   **if** CASE 2 **then**
7.   put all the channels in ML
8.   **else**
9.   **if** CASE 3 **then**
10.   **for** Each channel i in C_b **do**
11.   **if** $WT_i > \mu + \sigma$ AND $WT_i \leq 1$ **then**
12.   put channel i into BL
13.   **else**
14.   **if** $WT_i > \mu - \sigma$ AND $WT_i \leq \mu + \sigma$ **then**
15.   put channel i into ML
16.   **end if**
17.   **end if**
18.   **end for**
19.   **end if**
20.   **end if**
21. **end if**
22. Sort BL in decreasing order of channel weights
23. Sort ML in decreasing order of channel weights
24. **if** $| BL | > 0$ **then**
25.   Run Algorithm 3
26. **end if**
27. **if** A_s contains slot with unassigned channel **then**
28.   Run Algorithm 4
29. **end if**
30. **if** A_S still contains slots with unassigned channel **then**
31.   Go to step 26
32. **end if**

Multi Slot Channel Assignment Algorithm

Algorithm 3 MultiSlot channel assignment algorithm

INPUT: BL, the set of best available channels; A_s the set of allocated slot for all requests

OUTPUT: A_c, assigned channel set

$k \leftarrow$ index of unassigned slot
$i \leftarrow 0$
while $K \neq | A_s |$ **do**
  $ns = WT_i \times W_{factor}$
  if fractional part of $ns < \eta$ **then**
    floor (ns)
  else
    if fractional part of $ns \geq \eta$ **then**
      ceiling (ns)
    end if
  end if
  $j \leftarrow 0$
  while $j \leq ns$ AND $K \leq | A_s |$ **do**
    assign ch_i of BL to slot S_k
    $k \leftarrow k + 1$
    $j \leftarrow j + 1$
  end while
  $i \leftarrow i + 1$
  if $i > | BL |$ AND $| ML | ==$ Empty AND $K \leq | A_s |$ **then**
    $i \leftarrow 0$
  else
    Return
  end if
end while

Single Slot Channel Assignment Algorithm

Algorithm 4 SingleSlot channel assignment algorithm

INPUT: ML, the set of moderate channels; A_s the set of allocated slots for all requests

OUTPUT: A_c, assigned channel set

$i \leftarrow 0$
$j \leftarrow$ first index of unassigned channel slot
{NU denotes number of unassigned channel slots }
if $\mid ML \mid \geq NU$ **then**
  for Each unassigned slot S_j in A_s **do**
    assign ch_i to S_j
    $i \leftarrow i + 1$
    $j \leftarrow j + 1$
  end for
else
  if $\mid ML \mid < NU$ **then**
    for Each ch_i in ML **do**
      assign ch_i to S_j
      $i \leftarrow i + 1$
      $j \leftarrow j + 1$
    end for
  end if
end if

Backup Channel Assignment Algorithm

Algorithm 5 Backup channel assignment algorithm

INPUT: BL, best available channel list; ML, moderate channel list; AC_G, the set of allocated channels for each slot in GTS; AC_{BE}, the set of allocated channels for best effort traffic

OUTPUT: B_G, set of assigned backup channels for GTS; B_B, set of assigned backup channels for BE traffic

$A \leftarrow BL \cup ML$ {Channels in BL and ML are merged into A}
for $i \leftarrow 1$ to $| AC_G |$ **do**
    $k \leftarrow i$th channel in AC_G
    $j \leftarrow$ index of channel k in A
    if $j == | A |$ **then**
        assign A_1 to B_{Gi}
    else
        assign A_{j+1} to B_{Gi}
    end if
    $i \leftarrow i+1$
end for
for $i \leftarrow 1$ to $| AC_{BE} |$ **do**
    $k \leftarrow i^{th}$ channel in AC_{BE}
    $j \leftarrow$ index of channel k in A
    if $j == | A |$ **then**
        assign A_1 to B_{Bi}
    else
        assign A_{j+1} to B_{Bi}
    end if
    $i \leftarrow i+1$
end for

An Example Scenario: Finding BL and ML

Cbest

chi	6	2	7	1	9
WAi	.628	.716	.834	.722	.53

Mean = 0.681
SD = .109

BL

chi	7
WAi	.834

WAi > mean + SD

ML

chi	1	2	9
WAi	.722	.716	.628

mean-SD < WAi <= mean + SD

Here, .53 < mean – SD , so channel 9 is omitted from Cbest

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An Example Scenario: Assigning Channels and Backup channels to GTS Slots

Slot no	1	2	3	4	5	6	7	8
Node	RR1	RR2	RnR1	RnR2	RnR3	nRR1	nRR2	nRR3
Ch								
Bch								

BL

chi	7
WAi	.834

ML

chi	1	2	9
WAi	.722	.716	.628

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Assigning Channels and Backup channels to GTS Slots

Slot no	1	2	3	4	5	6	7	8
Node	RR1	RR2	RnR1	RnR2	RnR3	nRR1	nRR2	nRR3
Ch								
Bch								

Wfactor = 3

ns = WAi * Wfactor = 2.5 = 3

BL

chi	7
WAi	.834

ML

chi	1	2	9
WAi	.722	.716	.628

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Assigning Channels and Backup channels to GTS Slots

Slot no	1	2	3	4	5	6	7	8
Node	RR1	RR2	RnR1	RnR2	RnR3	nRR1	nRR2	nRR3
Ch	7	7	7					
Bch	1	1	1					

Wfactor = 3
ns = WAi * Wfactor = 2.5 = 3

BL

chi	7
WAi	.834

ML

chi	1	2	9
WAi	.722	.716	.628

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Assigning Channels and Backup channels to GTS Slots

Slot no	1	2	3	4	5	6	7	8
Node	RR1	RR2	RnR1	RnR2	RnR3	nRR1	nRR2	nRR3
Ch	7	7	7					
Bch	1	1	1					

No more channel in BL!!!
And there are Unassigned GTS slots
Remaining Slots will be assigned channel from ML

BL

chi	7
WAi	.834

ML

chi	1	2	9
WAi	.722	.716	.628

Assigning Channels and Backup channels to GTS Slots

Slot no	1	2	3	4	5	6	7	8
Node	RR1	RR2	RnR1	RnR2	RnR3	nRR1	nRR 2	nRR3
Ch	7	7	7	1	2	9		
Bch	1	1	1	2	9	7		

there are still Unassigned GTS slots

Remaining Slots will be assigned channels from BL again

BL

chi	7
WAi	.834

ML

chi	1	2	9
WAi	.722	.716	.628

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Assigning Channels and Backup channels to GTS Slots

Slot no	1	2	3	4	5	6	7	8
Node	RR1	RR2	RnR1	RnR2	RnR3	nRR1	nRR2	nRR3
Ch	7	7	7	1	2	9	7	7
Bch	1	1	1	2	9	7	1	1

All slots are assigned channels.

BL

chi	7
WAi	.834

ML

chi	1	2	9
WAi	.722	.716	.628

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Data Transmission Phase

DTP distributed into two parts:

- GTS slots
- PCAP

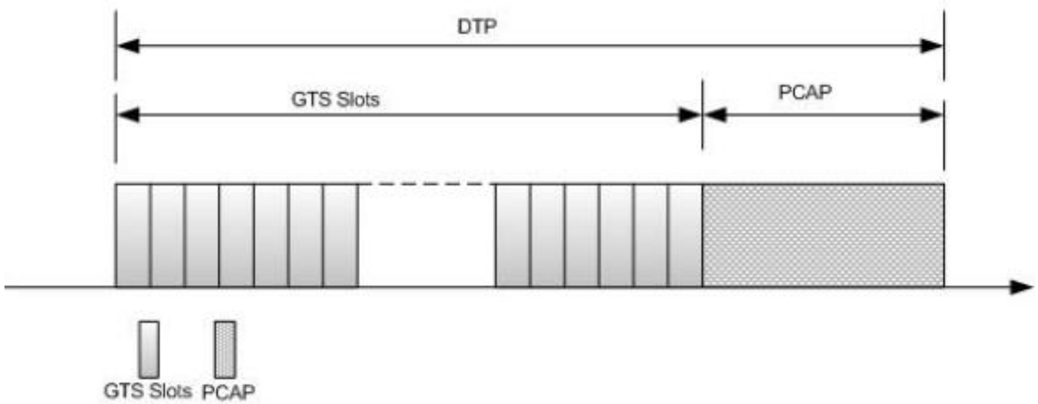

Fig.: Slot wstructure of DTP

Data Transmission Phase: GTS

- all the sensor nodes with RR, RnR and nRR types of packets transmit data in their own assigned GTS slots with their assigned channels.

Data Transmission Phase: PCAP

- The best effort traffic transmit data using a random back-off value for transmission,

$$T_{randomback-off} = [0, 2^t]$$

Where, t can be calculated as,

$$t = \frac{T_{rem}}{T_{in}} * f$$

Here, **T**$_{\mathbf{rem}}$ is the remaining packet lifetime, **T**$_{\mathbf{in}}$ is the initial packet lifetime and **f** is a dynamic multiplying factor.

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Backup Channel Switching Technique in GTS Slots

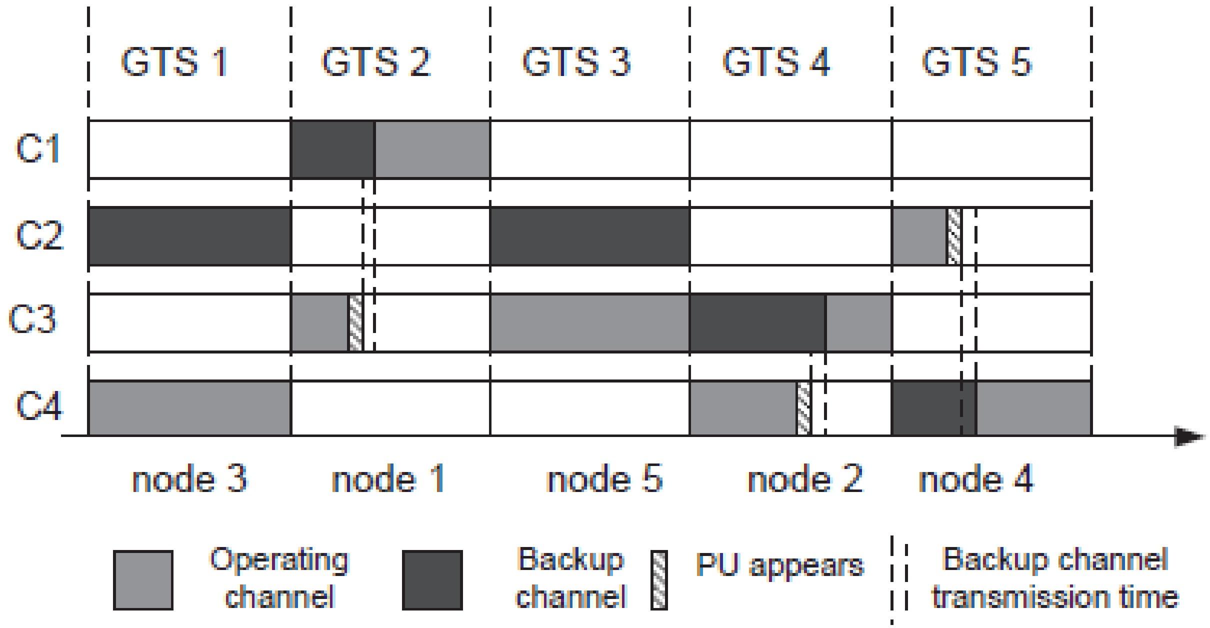

Fig.: Backup switching mechanism for GTS

Sleeping phase

- CH will be in inactive state with all other sensor nodes.
- If a longer sleeping phase is ensured then it eventually ensures energy efficiency.

Performance Evaluation

Simulation Parameters

Parameter	Value
Simulation area	1000m $\times$ 1000m
Number of sensor nodes	10 $\sim$ 250
Deployment type	Uniform random
Transmitting radius	200 m
Back-off mechanism	CSMA/CA
Number of Channels	10
Channel data rate	1mbps
Time for one channel sense	4ms
Superframe period	1 s
Number of slots in a superframe	128
Slot duration	7.68ms
CBR packet size	64Bytes
MAC layer model	adhocWifiMAC
Physical layer model	YansWifiPhy Model
Energy in channel sense	23.56mJ
Energy in receive mode	23.56mJ
Energy in transmit mode	18.6mJ
Initial energy of each node	100 Joule
Queue length	50
Simulation time	500 seconds

MQ-MAC Parameters

Parameter	Value
η	0.5
α	0.3
W_{factor}	3
μ_{up}	.8
σ_{max}	.1
f	3
K	5

Performance Metrics

- Average Packet Delivery Delay
- Ontime Reachability
- SU Blocking Rate
- LC Usage Probability
- Protocol Operation Overhead
- Average Energy Consumption

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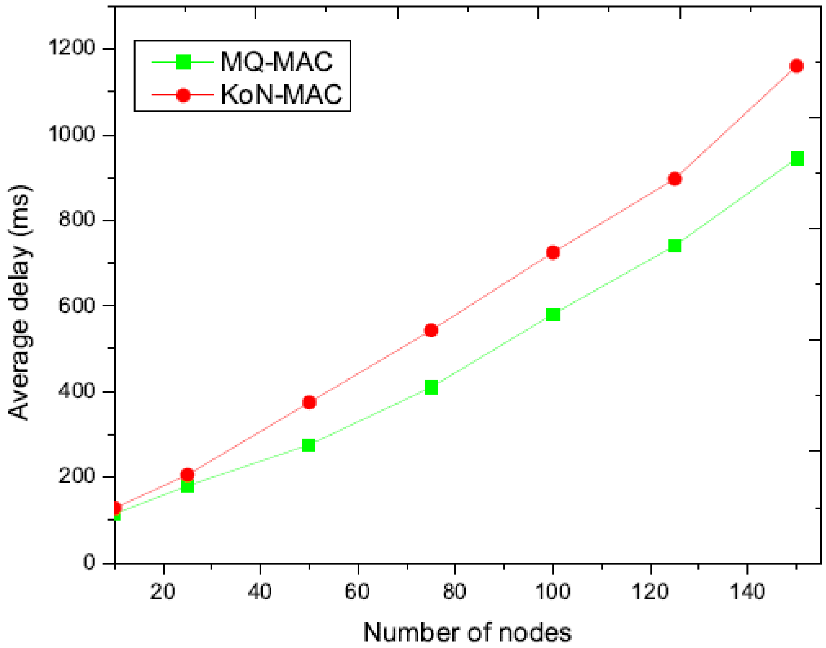
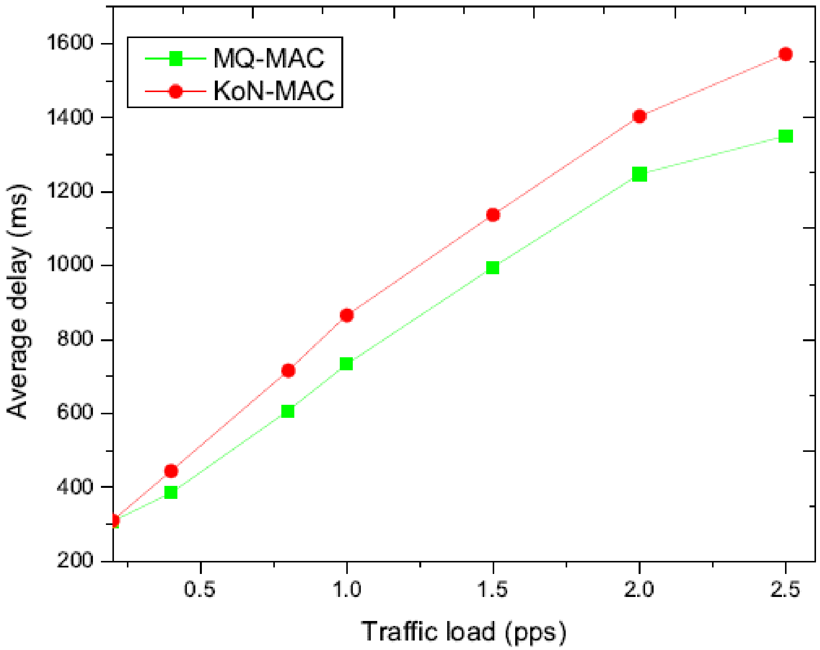
Average Packet Delivery Delay



With different number of nodes



With varying traffic load

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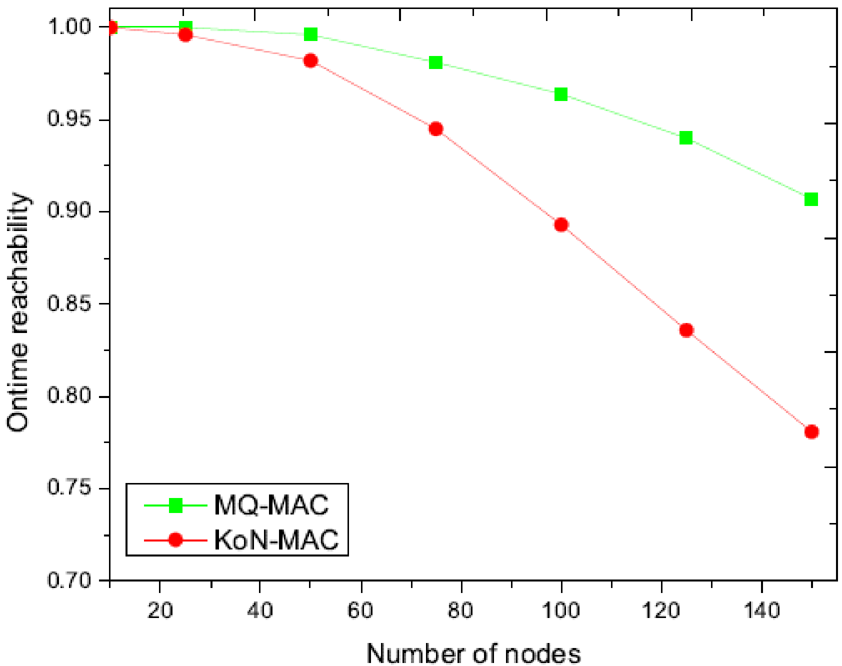
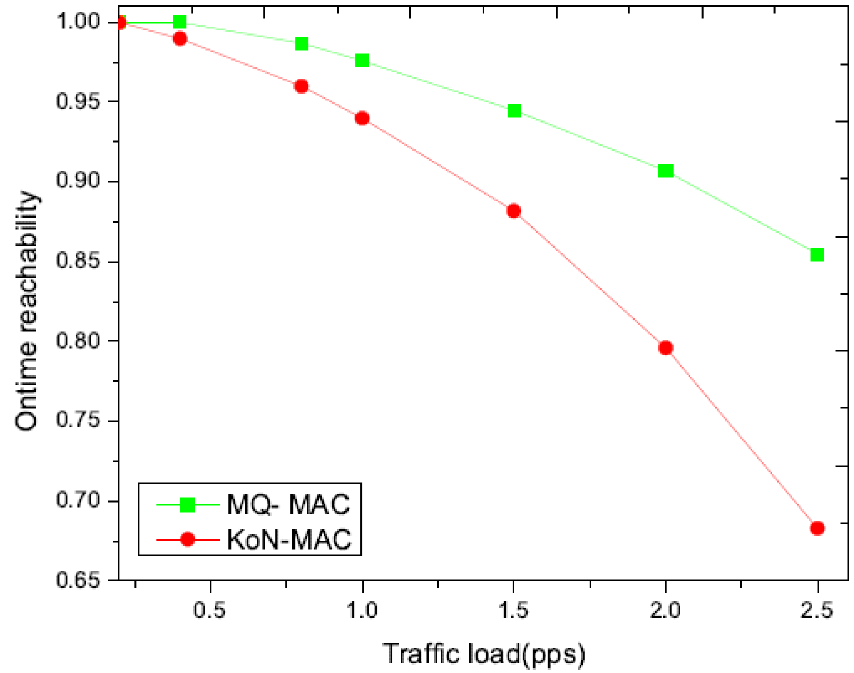
Ontime Reachability



With different number of nodes



With varying traffic load

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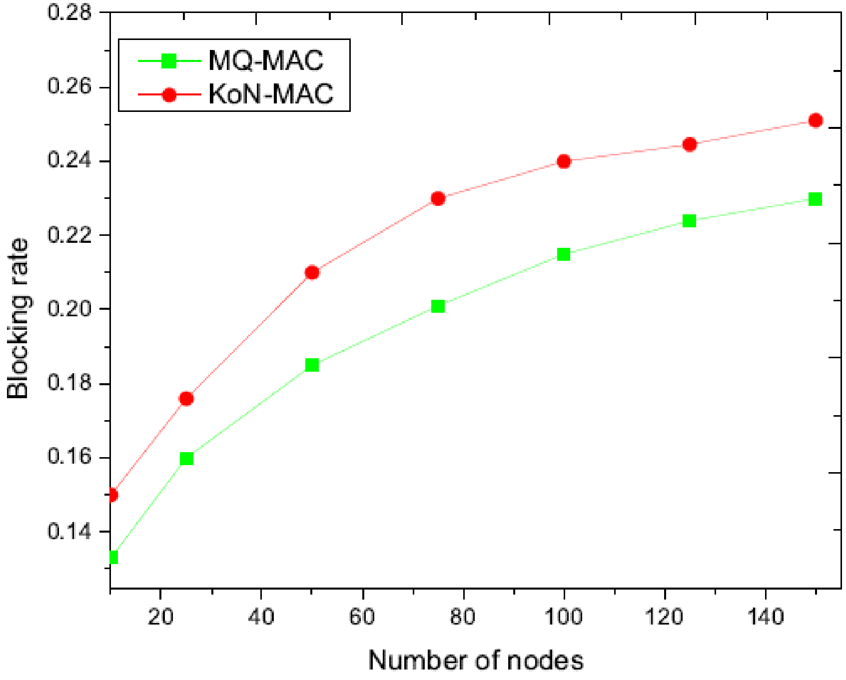
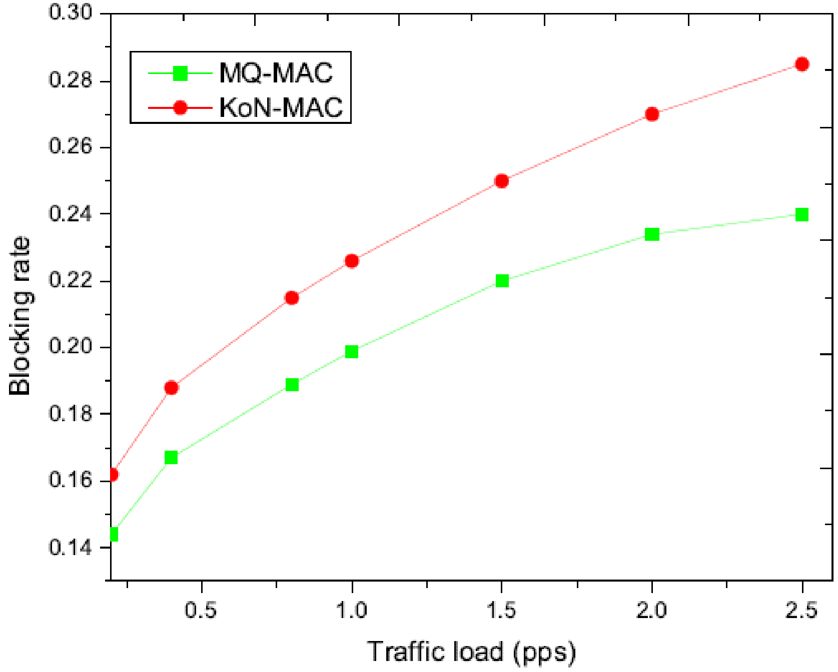
SU Blocking Rate



With different number of nodes



With varying traffic load

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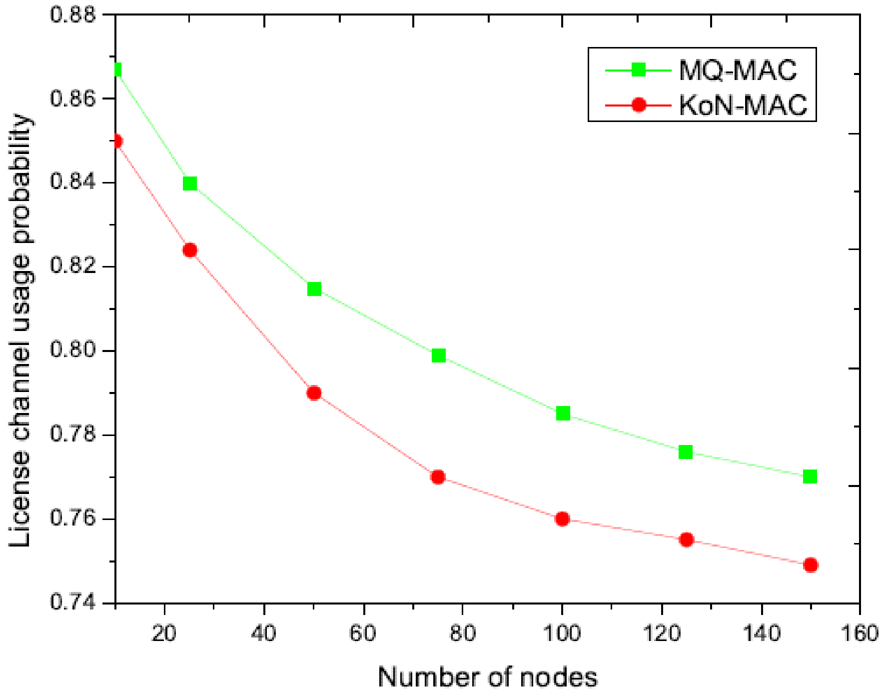
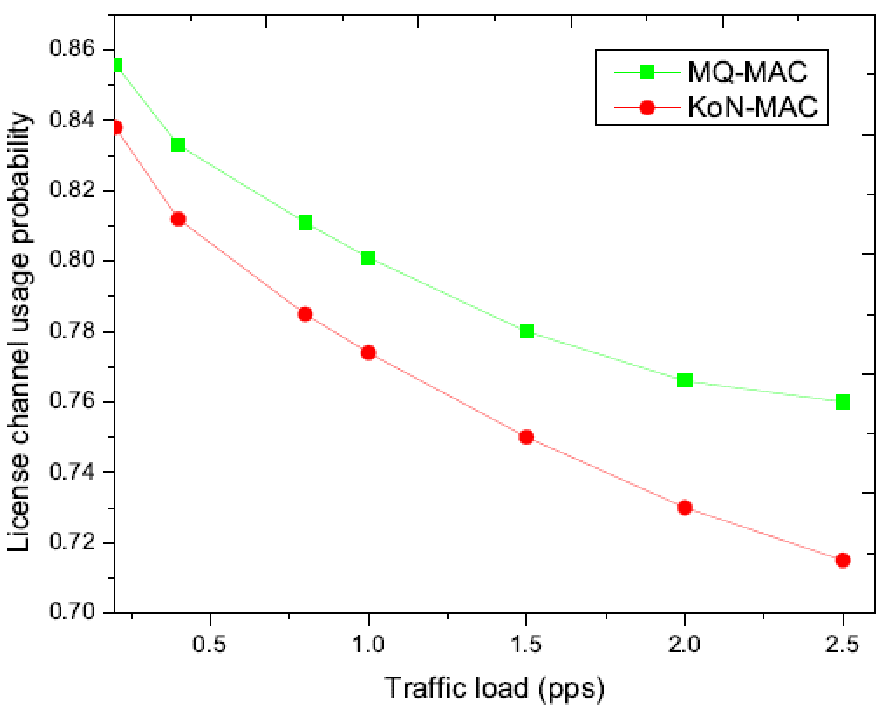
LC Usage Probability



With different number of nodes



With varying traffic load

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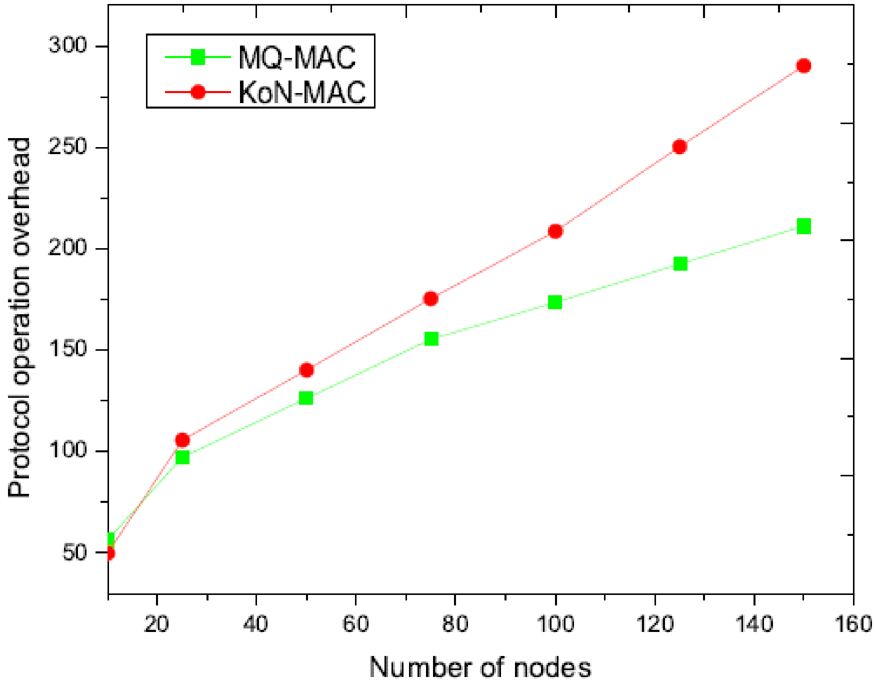
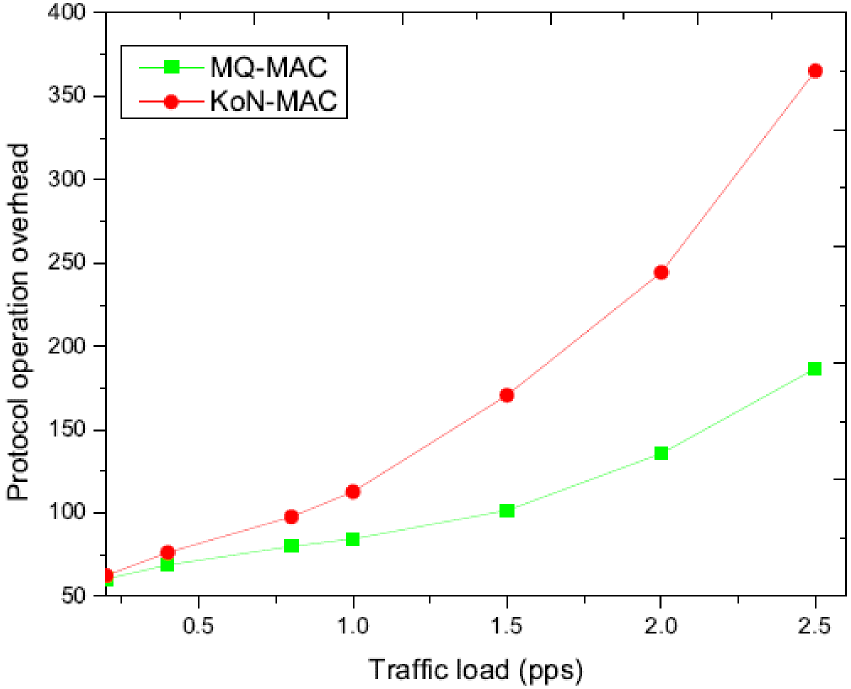
Protocol Operation Overhead

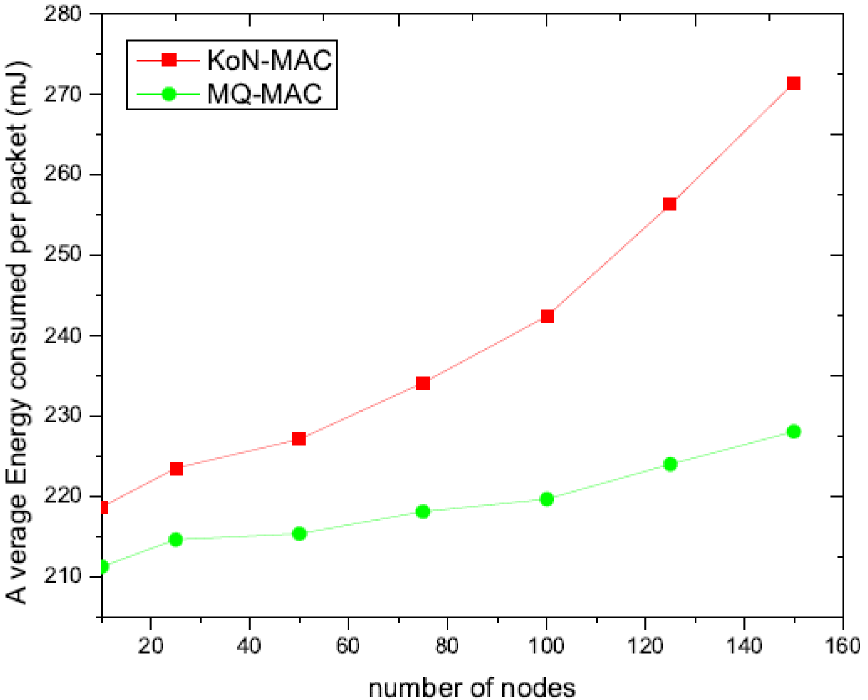


With different number of nodes

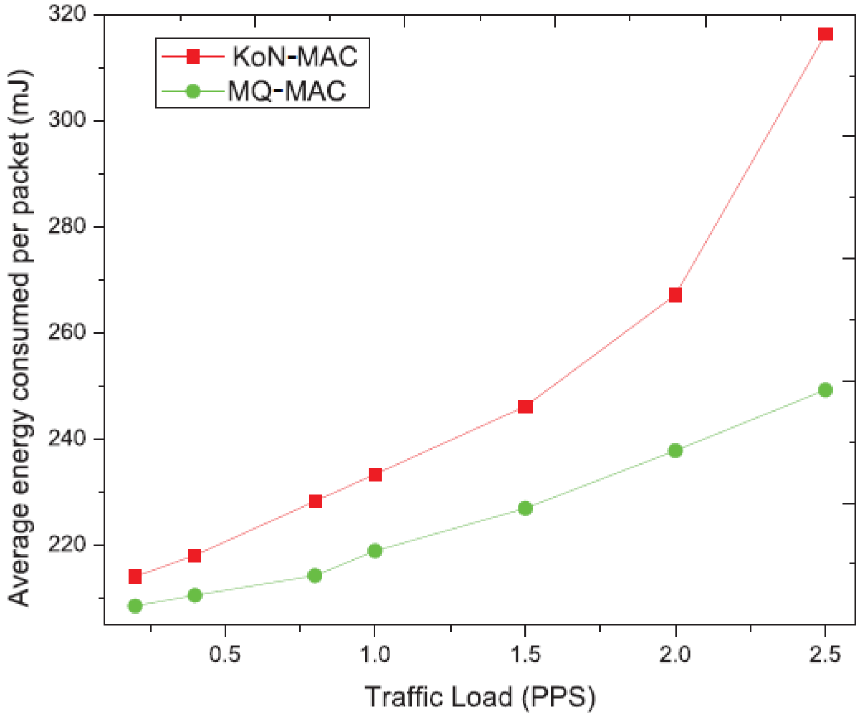


With varying traffic load

Average Energy Consumed



With different number of nodes



With varying traffic load

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Conclusion

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Thank You

Question???