Radio Co-location Aware Channel Assignments for Interference Mitigation in Wireless Mesh Networks

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WMN Model Considered

- A single Gateway WMN.
- Mesh-routers and mesh-clients.
- Multi-Radio Multi-Channel (MRMC) Deployment.
- Only inter mesh-router communication issues considered.

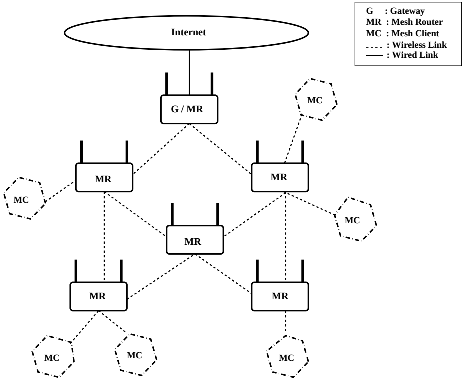
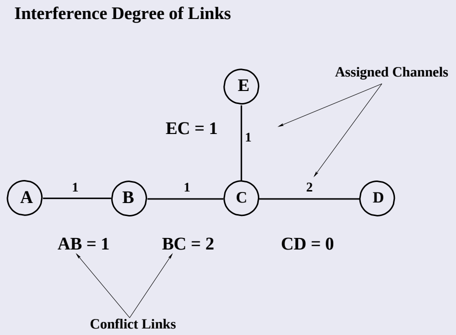


Figure: A Simplistic WMN Architecture

Concepts and Terminology I

Interference Degree

- The Interference Degree of a link (i, j), is the total number of links in WMN which are the conflict links of (i, j).



Concepts and Terminology II

Multi Radio Multi Channel Conflict Graph (MMCG)

- Conflict Graph for MRMC WMNs.
- Multiple radios / WMN Node.
- Several channels are available.
- Creation is complex.

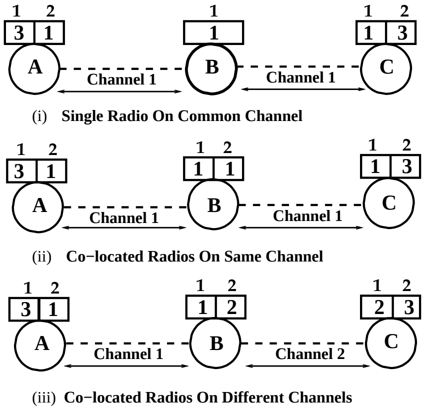
Channel Assignment (CA) Scheme

- CA can be understood as, $C_i = CA(i, R_i)$, where
  - Each node i, has random number of identical radios R_i.
  - $C_i \Rightarrow$ List of channels assigned to R_i.
- Assumption : Number of available channels $> (R_i)_{max}$

Radio Co-location Interference (RCI) I

Radio Co-location Scenarios

- Common Channel Scenarios
  - Fig. (i) → No RCI
    - Single Radio Common Channel at B (SRCC).
  - Fig. (ii) → RCI
    - Multiple Radios Common Channel at B (MRCC).
- Different Channel Scenarios
  - Fig. (iii) → No RCI
    - Multiple Radios Different Channels at B (MRDC).



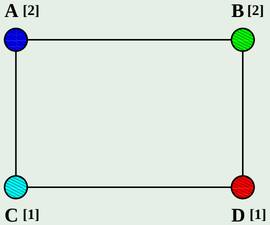
Radio Co-location Interference (RCI) II

Impact & Alleviation

- Spatially co-located radios cause RCI.
- Impact of RCI degrades network performance.
- Should be represented in MMCG.
- The Enhanced MMCG (E-MMCG) algorithm represents RCI while the Classical MMCG (C-MMCG) algorithm fails to do so [7].

Sample WMN Configuration

- G reflects a node centric view of the WMN.
- Vertices represent WMN nodes.
- Edges denote wireless links.
- All radios are operating on an identical channel (Channel_1).



Impact of RCI : Illustrated Through MMCGs

C-MMCG vs E-MMCG

- RCI conflict links → Red dotted lines in Figure 2.

Fig 1 : The C-MMCG G_c

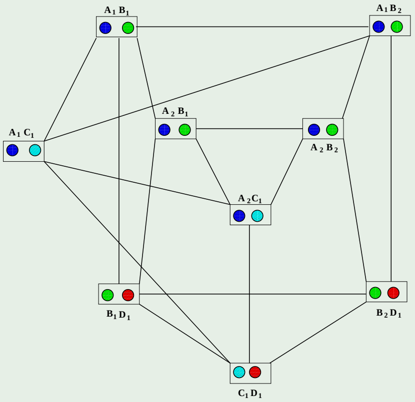
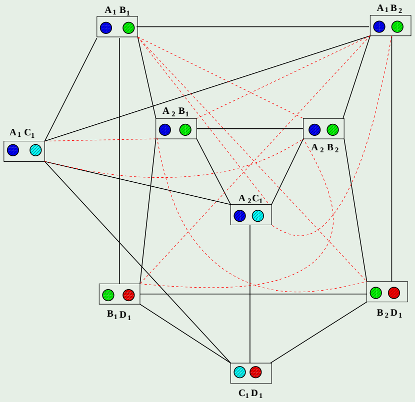


Fig 2 : The E-MMCG G_c



Radio Co-location Aware Channel Assignments

Features

Features of Radio Co-location Aware Channel Assignments (RCA CAs)

- RCI Mitigation through Radio Co-location Optimization (RCO) function.
- Equitable distribution of channels among radios in a WMN.
- Topology preserving.

The Proposed RCA CAs

Two RCA CAs are proposed

- RCA Optimized Independent Set (OIS) CA .
- RCA Elevated Interference Zone Mitigation (EIZM) CA.

RCA Optimized Independent Set CA

The Driving Ideas

- **Notion of Statistical Evenness in Channel Allocation**
  - CA performance has a Statistical Dimension.
  - Even distribution of channels across radios $\rightarrow$ Improved CA performance.
- **Emphasis on RCI Mitigation**

Statistical Evenness in Channel Allocation

Application & Validation

Idea Implementation

Concept of even distribution of channels across links is used in designing RCA OIS-CA

Idea Validation

Validation approach

- Propose OIS-CA and implement it.
- Compare OIS-CA with MaIS-CA (An Independent Set based CA).
  - Theoretically $\rightarrow$ Statistical Evenness.
  - Experimentally $\rightarrow$ ns-3 Simulations.

RCA Optimized Independent Set CA

OIS Algorithm

INPUT :

WMN GRAPH, G = (V,E)

CONFLICT GRAPH , $G_C = (V_C , E_C)$

AVAILABLE CHANNEL SET, CS

FIND ALL MUTUALLY EXCLUSIVE INDEPENDENT SETS (IS) OF VERTICES OF G_C

FOR ALL $IS_i \in IS$

- ASSIGN ALL VERTICES , CHANNEL ← (i % M) + 1

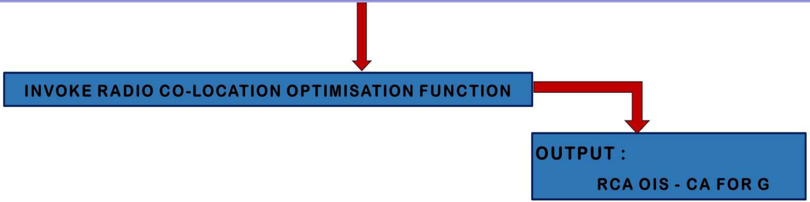
**** M IS THE NUMBER OF CHANNELS***

FOR EACH NODE

- **FIND CHANNELS ASSIGNED TO RADIOS.**
- **FIND ADJACENT NODES.**
- **FOR EACH ADJACENT NODE**
  - **IF RADIOS OF TWO NODES HAVE NO COMMON CHANNEL, CHANGE THE CHANNEL OF ONE OF THE RADIOS OF ADJACENT NODES SUCH THAT**
    - **TID IS NOT INCREASED.**
    - **CONNECTIVITY OF ADJACENT NODE IS PRESERVED.**

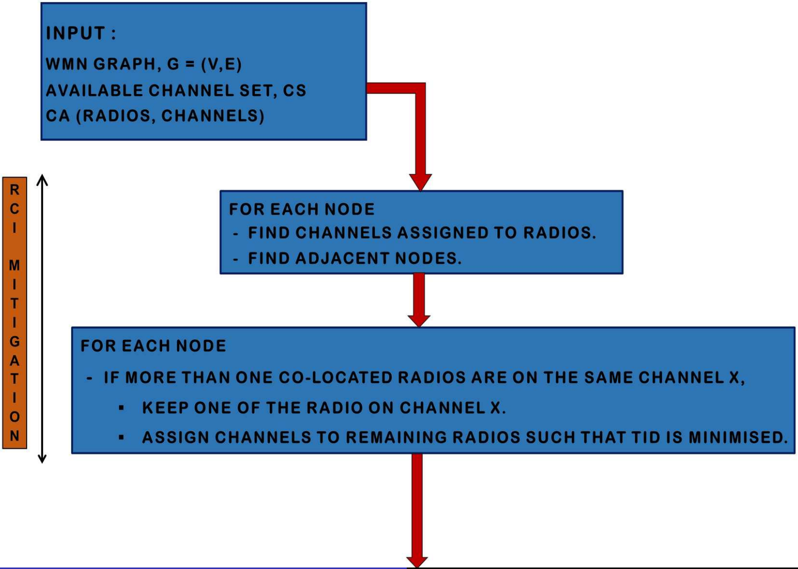
RCA Optimized Independent Set CA

OIS Algorithm



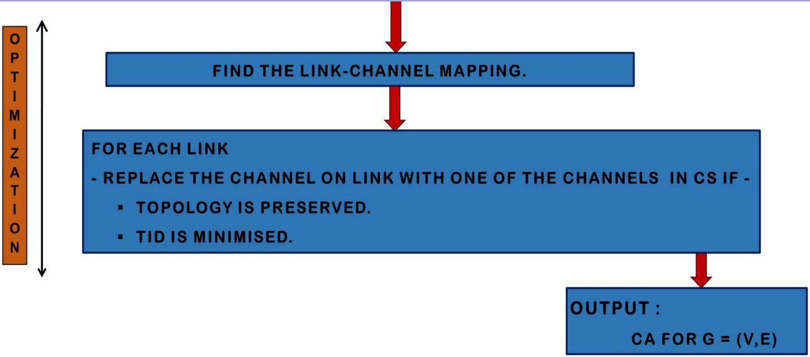
Radio Co-location Optimization

RCO Algorithm



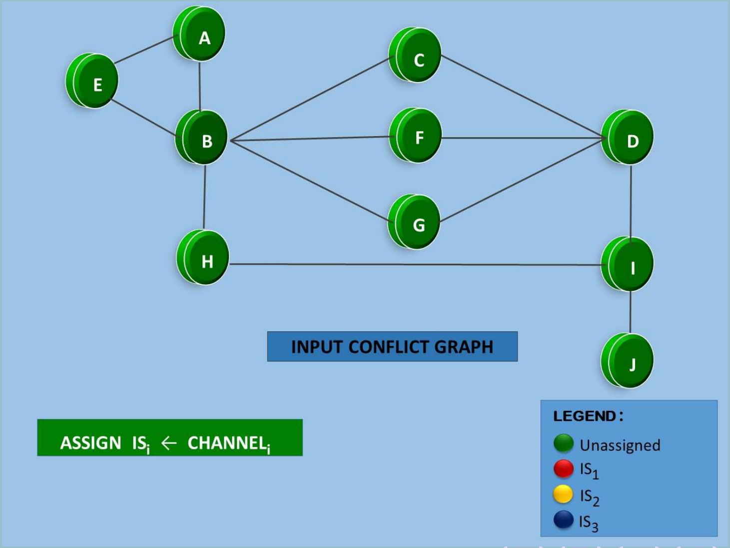
Radio Co-location Optimization

RCO Algorithm



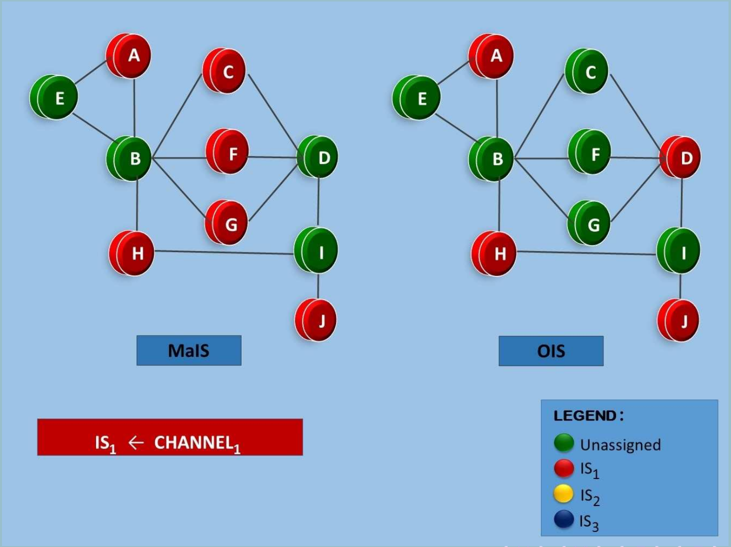
OIS vs MaIS : Independent Set Selection

Input Conflict Graph



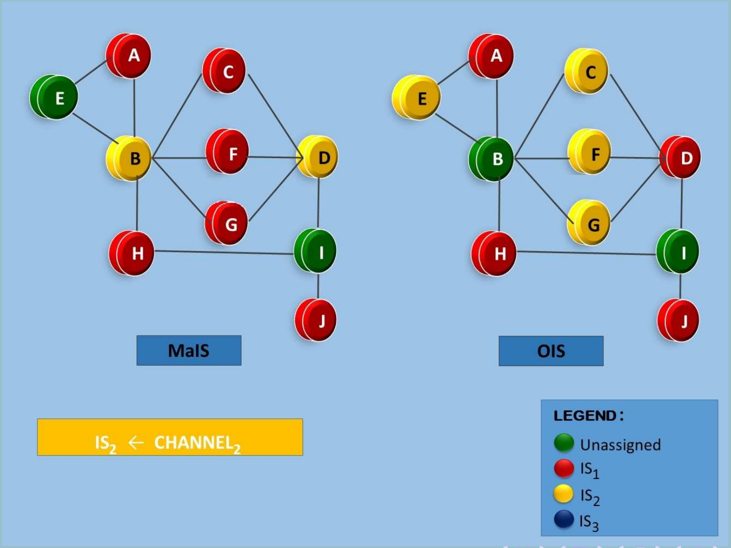
OIS vs MaIS : Independent Set Selection

Independent Set 1



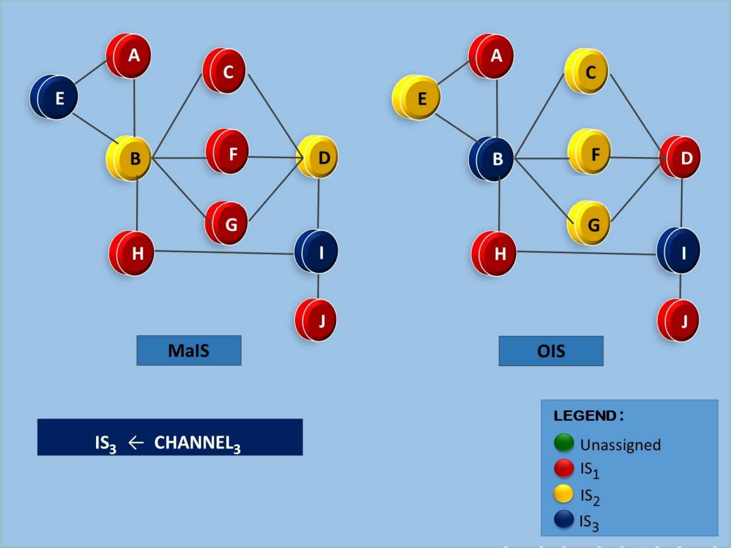
OIS vs MaIS : Independent Set Selection

Independent Set 2



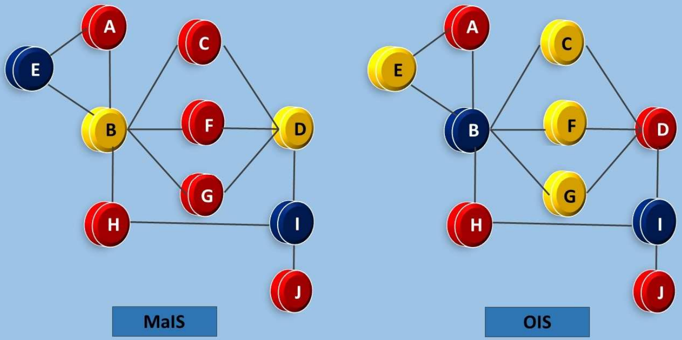
OIS vs MaIS : Independent Set Selection

Independent Set 3



OIS vs MaIS : Independent Set Selection

Measuring Statistical Evenness



- $IS_1 : IS_2 : IS_3 \rightarrow 6:2:2$
- Standard Deviation = 1.89

- $IS_1 : IS_2 : IS_3 \rightarrow 4:4:2$
- Standard Deviation = 0.94

OIS vs MaIS : Independent Set Selection

Is Channel Distribution Equitable ?

Ratio of Channel Distribution across Radios

Grid Size	Num of Radios	R_{C1} : R_{C2} : R_{C3} MaIS	OIS
5×5	50	1.00 : 1.63 : 1.94	1.00 : 1.06 : 1.06
6×6	72	1.00 : 1.33 : 1.66	1.00 : 1.09 : 1.33
7×7	98	1.00 : 1.56 : 1.69	1.00 : 1.00 : 1.16
8×8	128	1.00 : 1.48 : 1.64	1.00 : 1.00 : 1.28
9×9	162	1.00 : 1.58 : 1.57	1.08 : 1.00 : 1.29

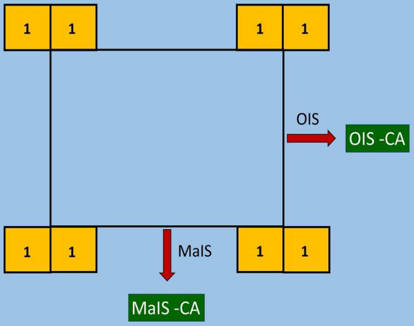
- 2 radios/node, 3 orthogonal channels $C_1,\ C_2\ \&\ C_3$
- Statistical Evenness of a CA $\rightarrow R_{C1} : R_{C2} : R_{C3}$.
  - $R_{Ch} \rightarrow$ Number of radios operating on channel Ch
  - Ratio normalized by smallest value.
- MaIS $\rightarrow$ Skewed distribution of channels.

STATISTICAL EVENNESS $\rightarrow$ OIS $>$ MaIS

OIS vs MaIS : A Theoretical Illustration

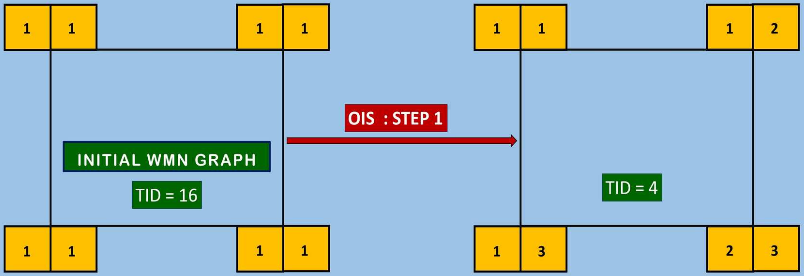
Sample WMN

INITIAL WMN GRAPH
- **4 NODES**
- **2 RADIOS / NODE**
- **3 CHANNELS AVAILABLE**
- **INITIALLY ALL NODES ON CHANNEL$_1$**



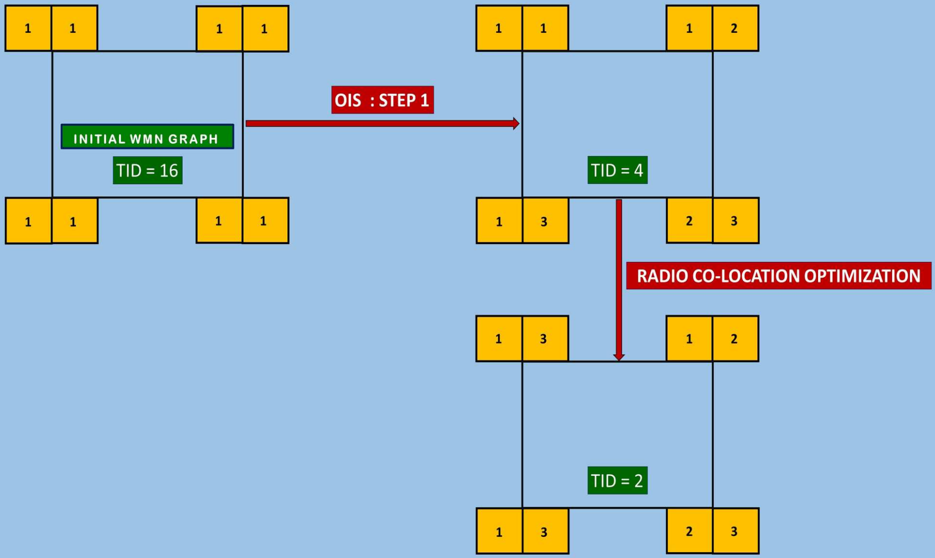
OIS vs MaIS : A Theoretical Illustration

OIS Step 1



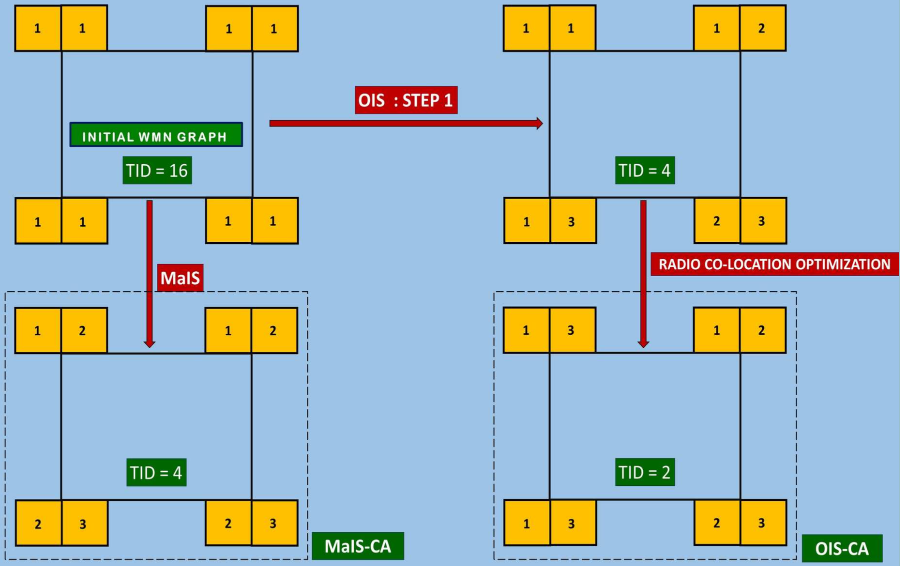
OIS vs MaIS : A Theoretical Illustration

Radio Co-location Optimization



OIS vs MaIS : A Theoretical Illustration

Channel Assignment Comparison



Simulation Setup

WMN Topologies & CA Schemes

WMN Topologies

- 5×5 grid WMN (GWMN).
- Random WMN (RWMN) of 50 nodes spread across an area of $1500m \times 1500m$.

CA Schemes Considered

- BFS-CA $\rightarrow$ A Breadth First Search based CA.
- MaIS-CA $\rightarrow$ A Maximum Independent Set based CA.
- OIS-CA $\rightarrow$ RCA Optimized Independent Set based CA.
- OIS-N-CA $\rightarrow$ Non-RCA version of OIS.

Simulation Setup

Data Traffic Characteristics

Flow Types

- Grid WMN.
  - 4-Hop Flows & 8-Hop Flows.
- Random WMN.
  - 3-Hop Flows to 10-Hop Flows.

Transport Layer Protocols

- TCP $\rightarrow$ ns-3 BulkSendApplication.
- UDP $\rightarrow$ ns-3 UdpClientServer.

Network Metrics Observed

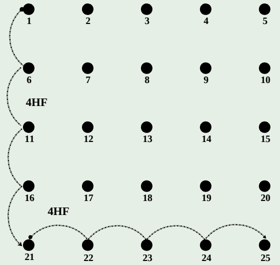
- Network Aggregate Throughput (Throughput).
- Packet Loss Ratio (PLR).
- Mean Delay (MD).

Simulation Setup
Test Scenarios

Grid WMN Test Cases

1. D2 → Two concurrent 8-Hop flows.
2. H5 → Five concurrent 4-Hop flows (Rows).
3. V5 → Five concurrent 4-Hop flows (Columns).
4. H4V4 →Eight concurrent 4-Hop flows (Combinations).
5. H5V5 → Ten concurrent 4-Hop flows (H5 & V5).
6. H5V5D2 → Twelve concurrent flows. (D2, H5 & V5).

Grid WMN Layout



Simulation Setup

Test Scenarios

Random WMN Test Cases

Test Cases → Concurrent multi-hop flows of 3 to 10 hop counts.

1. TC4 → 4 concurrent multi-hop flows.
2. TC8 → 8 concurrent multi-hop flows.
3. TC12 → 12 concurrent multi-hop flows.
4. TC16 → 16 concurrent multi-hop flows.
5. TC20 → 20 concurrent multi-hop flows.

Simulation Setup

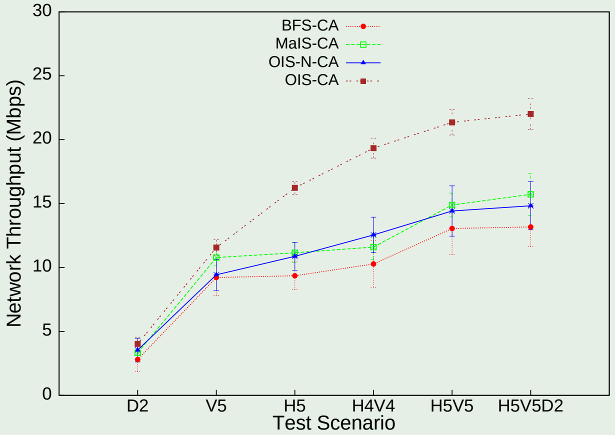
Simulation Parameters

ns-3 Simulation Parameters

Parameter	Value
Radios/Node	GWMN: 2, RWMN: 3
Range Of Radios	250 mts
IEEE Standard	GWMN: 802.11g RWMN: 802.11n
Available Orthogonal Channels	GWMN: 3 (2.4 GHz) RWMN: 4 (5 GHz)
Transmitted File Size	GWMN: 10 MB RWMN: 1 MB
Maximum 802.11g/n Phy Datarate	54 Mbps
Maximum Segment Size (TCP)	1 KB
Packet Size (UDP)	GWMN: 1 KB RWMN: 512 Bytes
MAC Fragmentation Threshold	2200 Bytes
RTS/CTS	Enabled
Packet Interval (UDP)	50ms
Routing Protocol Used	OLSR
Loss Model	Range Propagation
Rate Control	Constant Rate

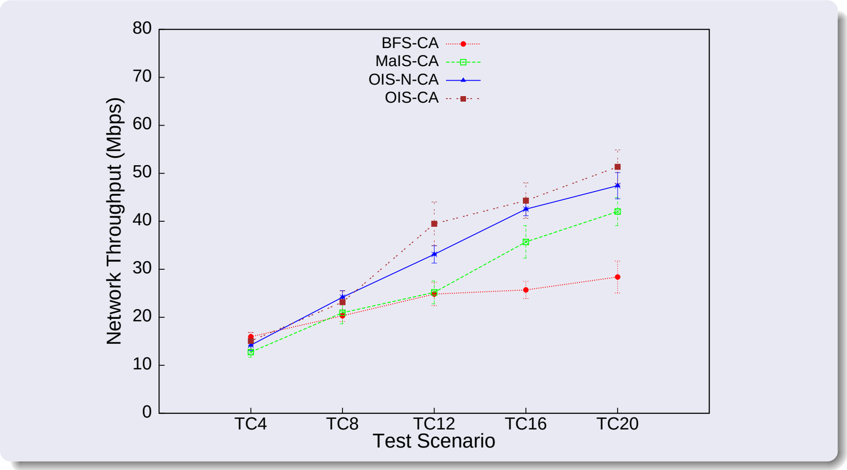
OIS Performance Evaluation

GWMN Throughput



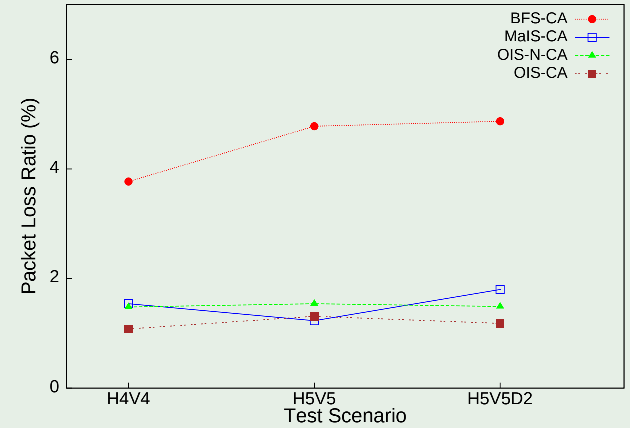
OIS Performance Evaluation

RWMN Throughput



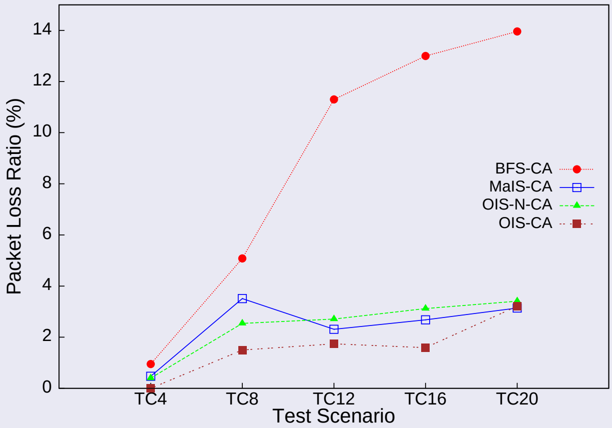
OIS Performance Evaluation

PLR in GWMN



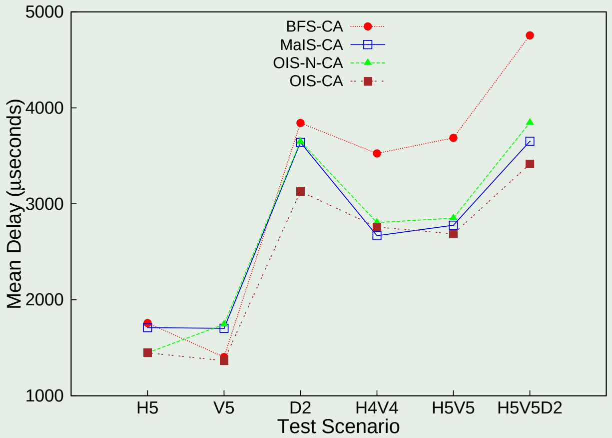
OIS Performance Evaluation

PLR in RWMN

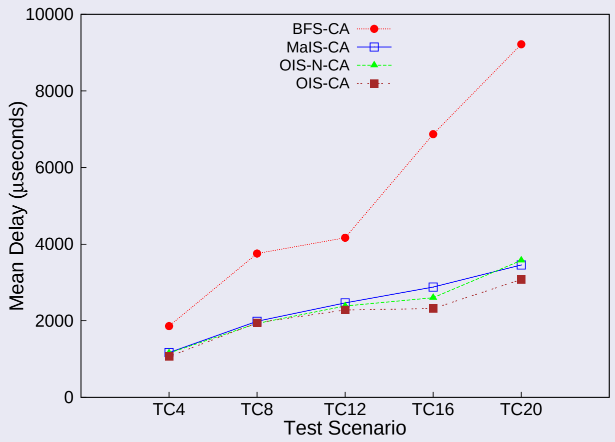


OIS Performance Evaluation

MD in GWMN



OIS Performance Evaluation
MD in RWMN



RCA Elevated Interference Zone Mitigation CA

Motivation

Factors Contributing To Idea Development

- Impact of interference varies within a wireless network.
- SINR levels at different locations differ.

The Driving Idea

- Localized pockets of high interference → Performance bottlenecks.
  - Named → Elevated Interference Zones (EIZ)
  - Interference alleviation at EIZ → Enhanced performance.
- Emphasis on RCI mitigation

Features of EIZM CA

Spatio-statistical Design

Spatial Features

Focuses on localized Elevated Interference Zones.

- Identifies EIZ in a WMN through its Conflict Graph.
- Assigns channels to EIZ based on severity of interference.
- Correlates TID with SINR.

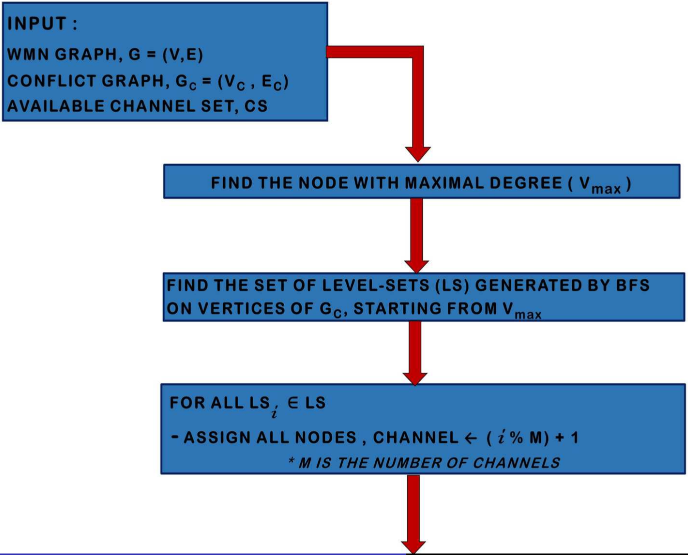
Statistical Evenness

Aimed at equitable distribution of channels across radios.

- Most CA schemes start with a default channel assignment.
- Causes overuse of default channel → Skewed distribution.
  - eg. MaIS-CA, BFS-CA, CEN-CA, CLQ-CA etc.
- EIZM-CA divides MMCG nodes into level Sets (BFS traversal).
  - Adjacent Level Set nodes → Orthogonal channels.
  - Improved distribution of channels.

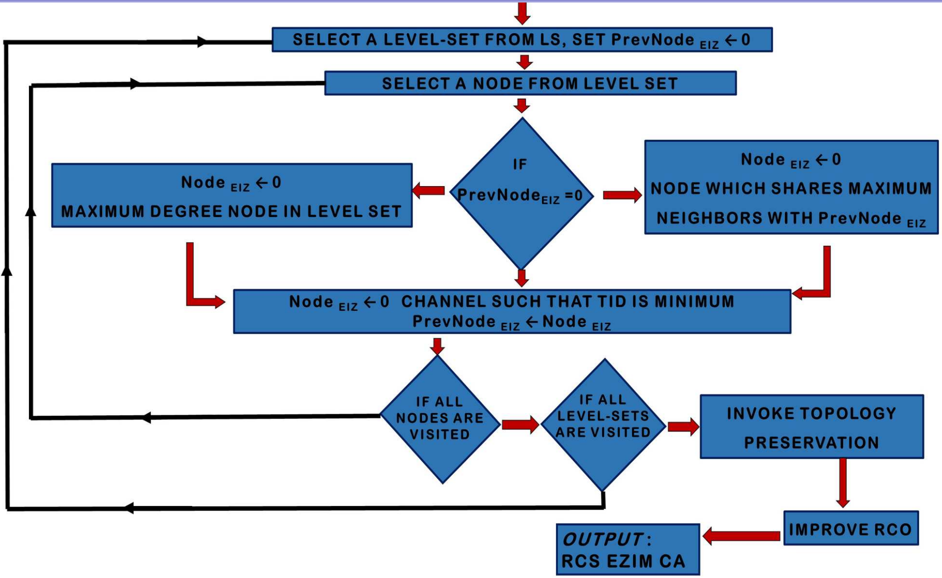
RCA Elevated Interference Zone Mitigation CA

EIZM Algorithm



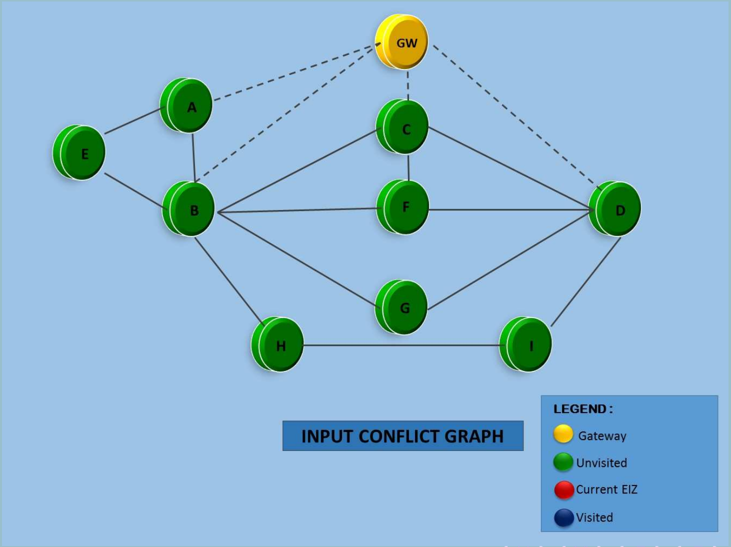
RCA Elevated Interference Zone Mitigation CA

EIZM Algorithm



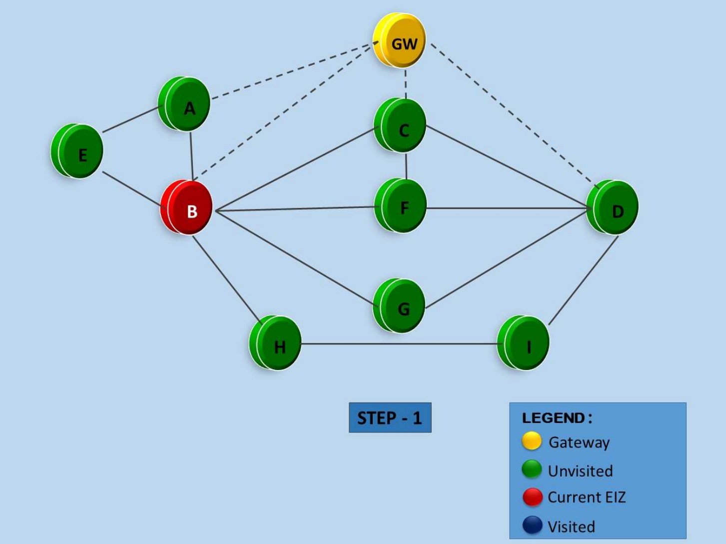
EIZ Selection Sequence

Input Conflict Graph

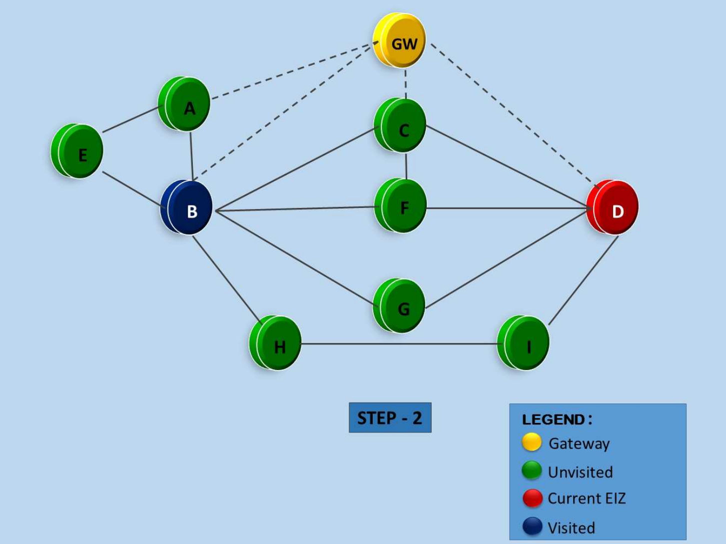


EIZ Selection Sequence

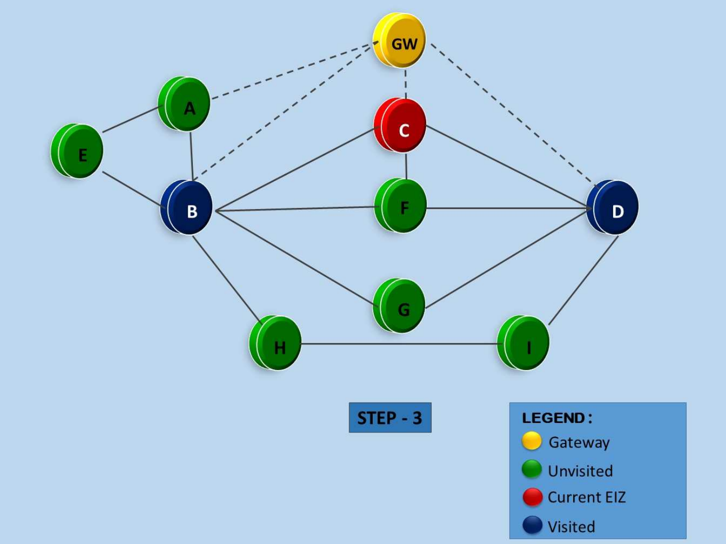
Step 1



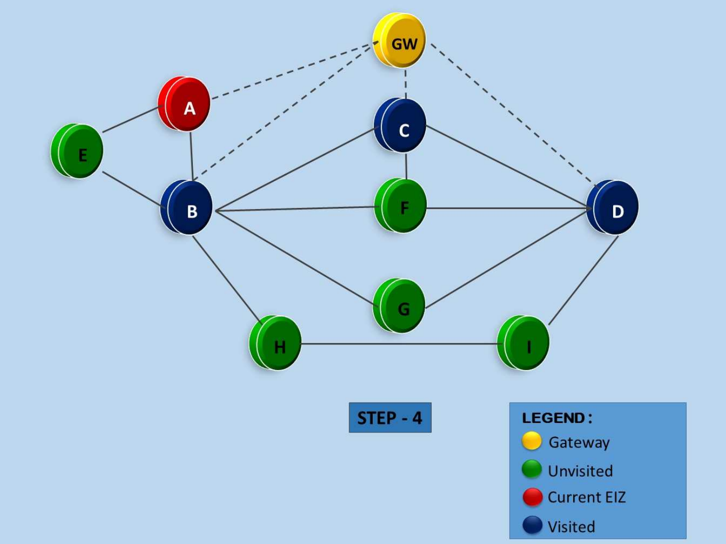
EIZ Selection Sequence
Step 2



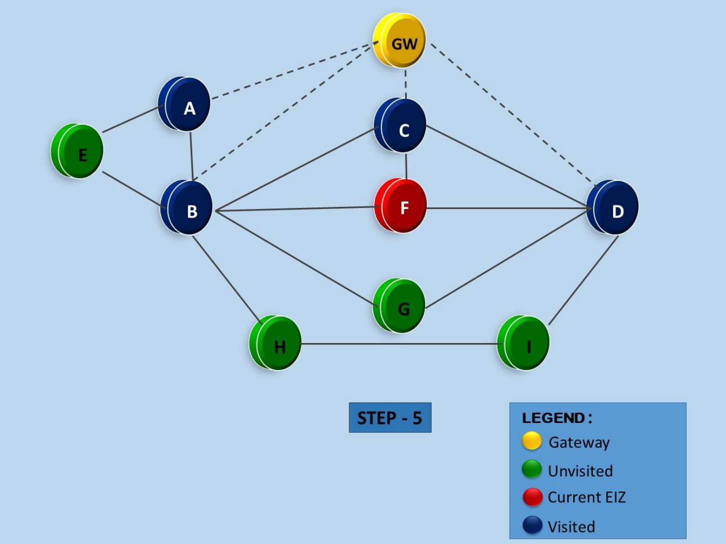
EIZ Selection Sequence
Step 3



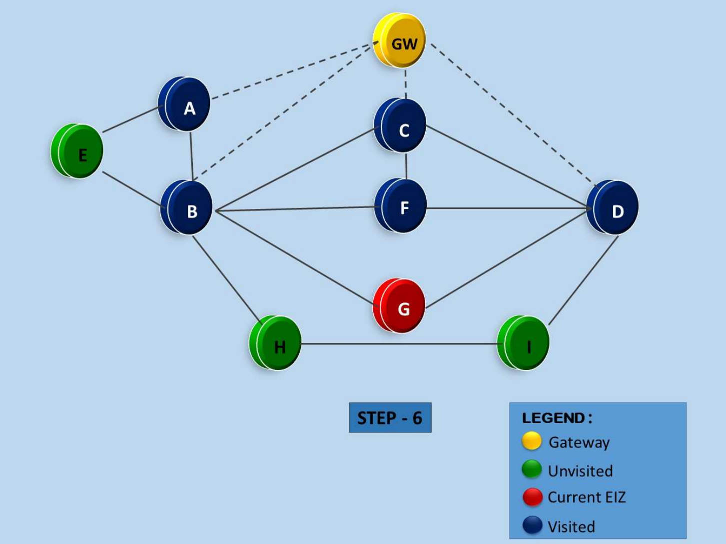
EIZ Selection Sequence
Step 4



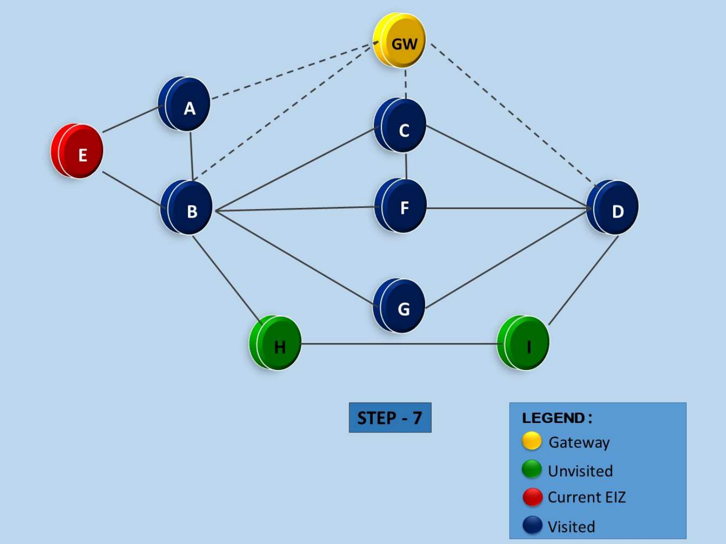
EIZ Selection Sequence
Step 5



EIZ Selection Sequence
Step 6

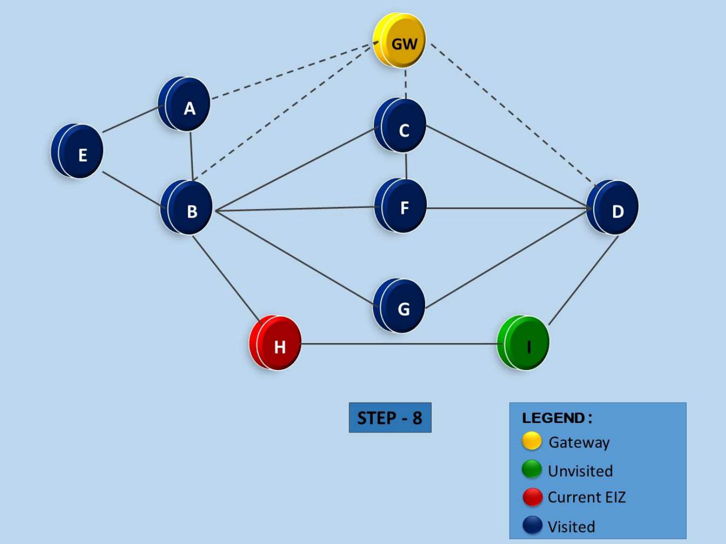


EIZ Selection Sequence
Step 7



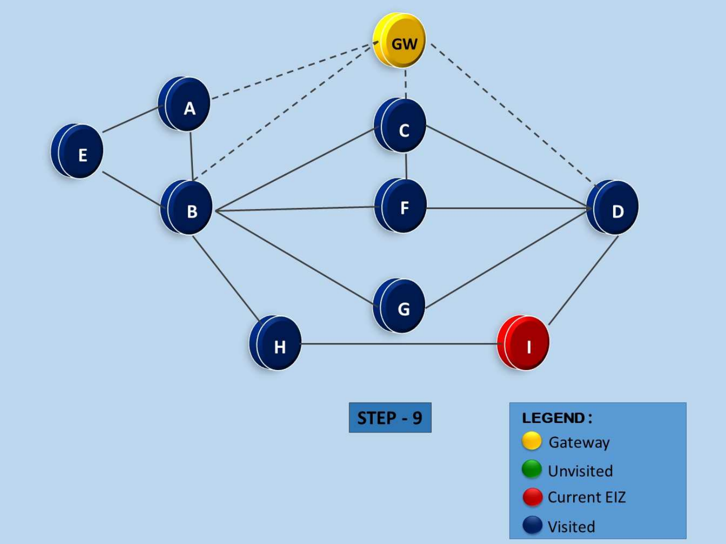
EIZ Selection Sequence

Step 8



EIZ Selection Sequence

Step 9



EIZM : A Theoretical Illustration

Sample WMN

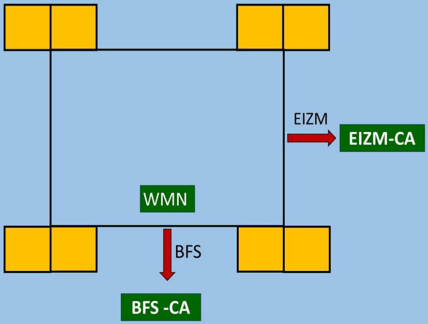
INITIAL WMN GRAPH

- 4 NODES

- 2 RADIOS / NODE

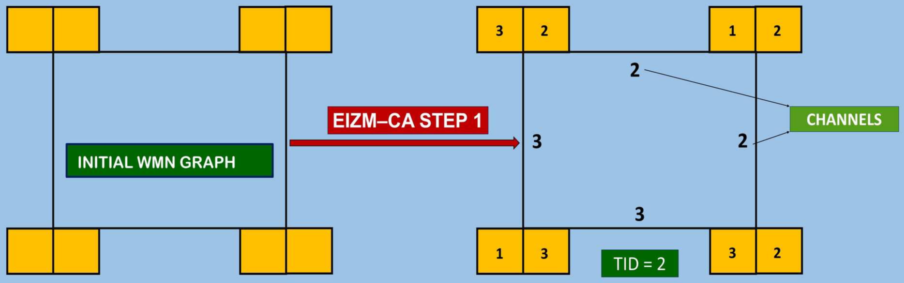
- 3 CHANNELS AVAILABLE

- NO INITIAL CHANNEL ASSIGNMENT TO RADIOS



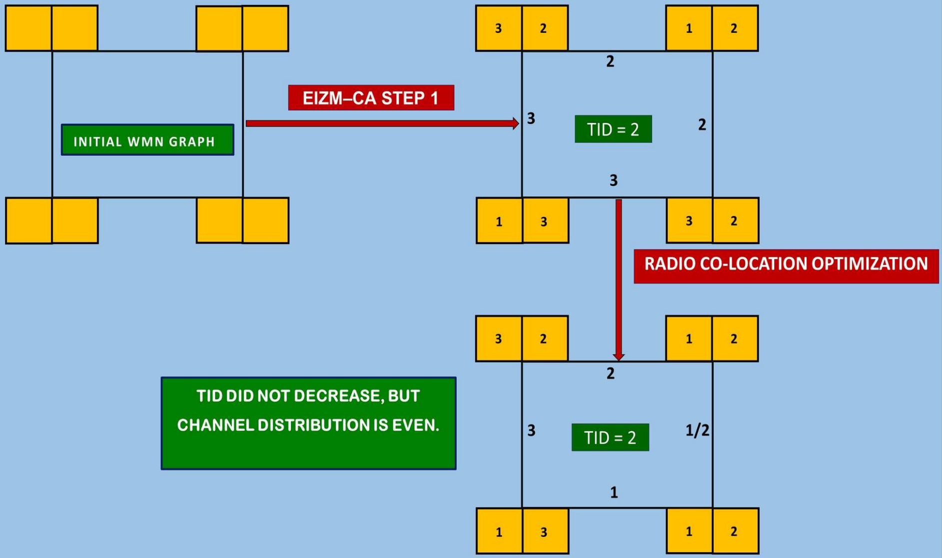
EIZM : A Theoretical Illustration

EIZM Step 1



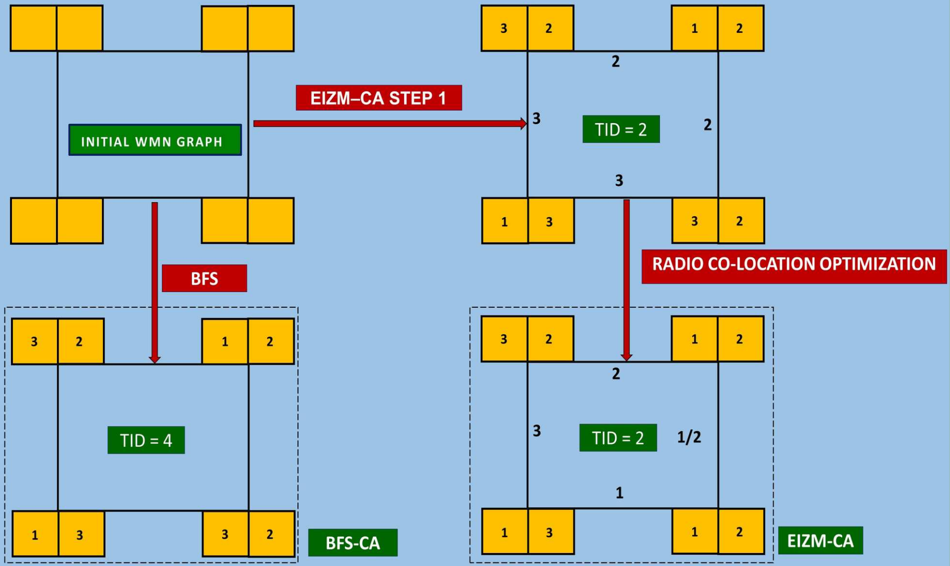
EIZM : A Theoretical Illustration

Radio Co-location Optimization



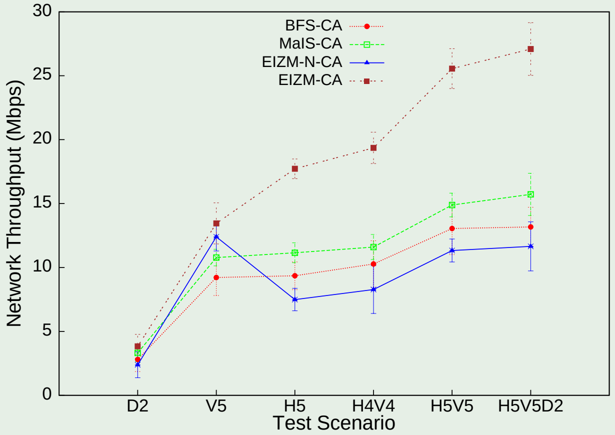
EIZM : A Theoretical Illustration

Channel Assignment Comparison : BFS-CA



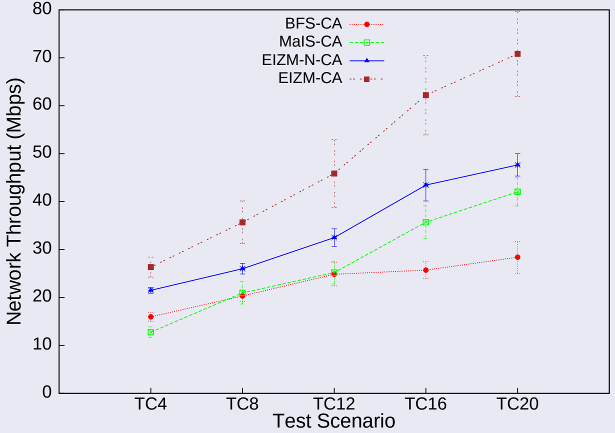
EIZM Performance Evaluation

GWMN Throughput

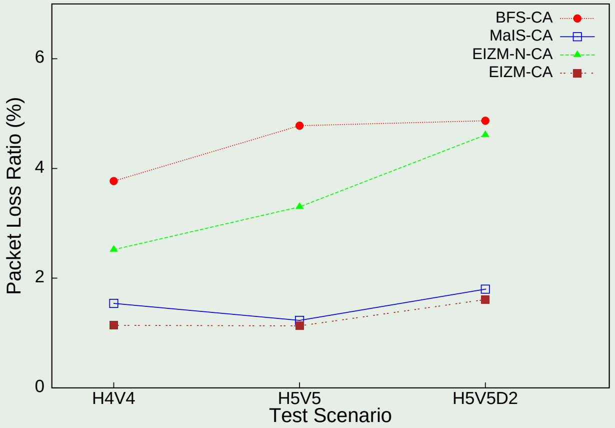


EIZM Performance Evaluation

RWMN Throughput

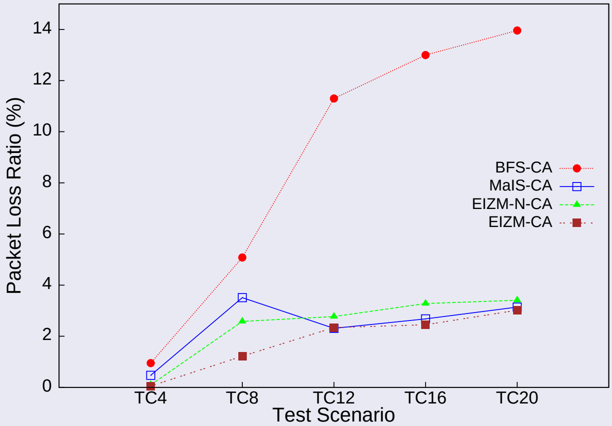


EIZM Performance Evaluation
PLR in GWMN



- RTS/CTS is enabled for the one-way UDP flows.
- Hence magnitude of PLR values is less prominent.

EIZM Performance Evaluation
PLR in RWMN



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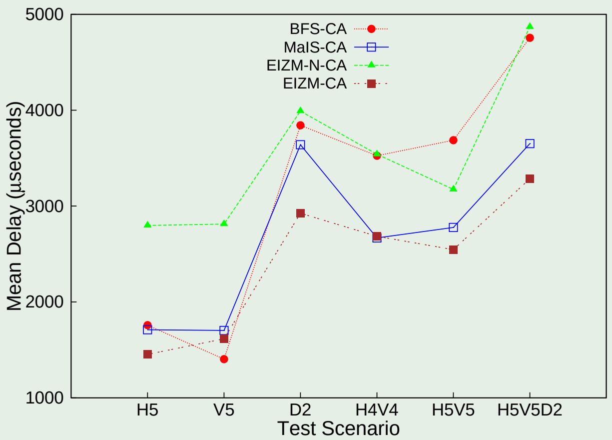
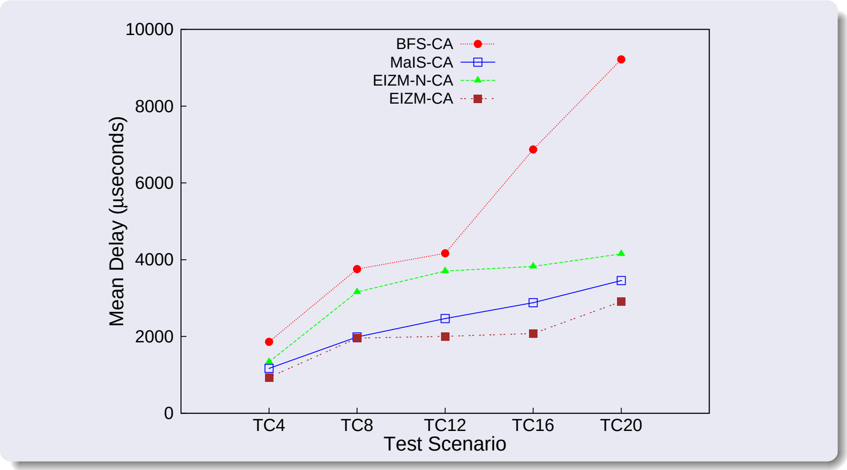
EIZM Performance Evaluation

MD in GWMN



EIZM Performance Evaluation

MD in RWMN



Quantitative Analysis of Results

Maximum Increase in Throughput

- EIZM-CA over MaIS-CA $\rightarrow 72\%$
- EIZM-CA over BFS-CA $\rightarrow 149\%$
- OIS-CA over MaIS-CA $\rightarrow 43\%$
- OIS-CA over BFS-CA $\rightarrow 81\%$

Maximum Decrease in MD

- EIZM-CA over MaIS-CA $\rightarrow 68\%$
- EIZM-CA over BFS-CA $\rightarrow 28\%$
- OIS-CA over MaIS-CA $\rightarrow 41\%$
- OIS-CA over BFS-CA $\rightarrow 19\%$

Maximum Decrease in PLR

- EIZM-CA over MaIS-CA $\rightarrow 11\%$
- EIZM-CA over BFS-CA $\rightarrow 81\%$
- OIS-CA over MaIS-CA $\rightarrow 41\%$
- OIS-CA over BFS-CA $\rightarrow 88\%$

EIZM-CA vs OIS-CA

- Throughput $\rightarrow$ EIZM-CA $>$ OIS-CA
- PLR $\rightarrow$ EIZM-CA $\approx$ OIS-CA
- MD $\rightarrow$ EIZM-CA $\approx$ OIS-CA

Conclusions

Radio Co-location Aware Channel Assignments

- EIZM-CA & OIS-CA significantly outperform reference CAs.
  - Radio Co-location Optimization.
  - Equitable distribution of channels across radios.
- EIZM-CA performs better than OIS-CA.
  - Spatio-statistical CA design > Purely statistical CA design.

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Thank You

QUERIES ?