Reliable Prediction of Channel Assignment Performance in Wireless Mesh Networks

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Overview

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.

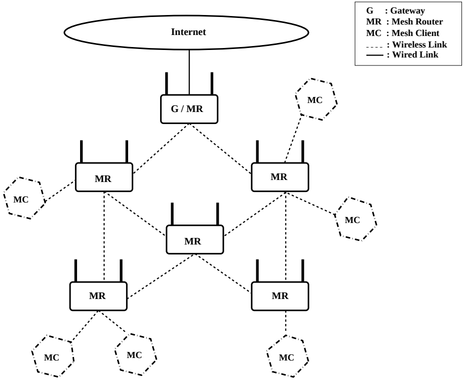


Figure : A Simplistic WMN Architecture

CA Schemes in WMNs

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 $> (R_i)_{max}$

Role of CA Schemes

- Interference $\rightarrow$ Most debilitating factor in network performance.
- Minimizing interference in WMNs is a primary objective.
- Mainly achieved through a prudent channel assignment (CA) scheme, which
  - Enhances network capacity.
  - Reduces end to end latency.
  - Reduces data packet loss.

Selecting the Right CA Scheme for a WMN

- Multitude of CA schemes in research literature.
- Choosing an efficient CA for a WMN $\rightarrow$ A tedious task.
- Absence of CA performance prediction techniques.

Existing Interference Estimation Schemes

An Evaluation

TID

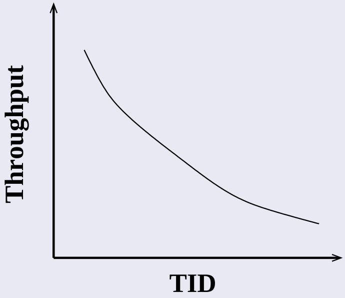
- Conventional approach for estimating interference.
- Considers spatial proximity of links for interference estimation.
- Computed by halving the summation of the *Interference Degree* of all the links in WMN.
- Not a reliable metric.

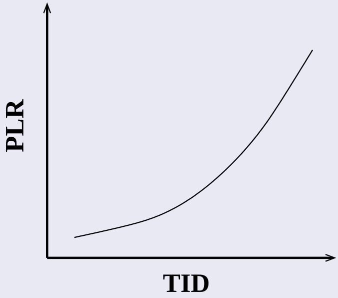
CDAL$_{cost}$

- A new approach for estimating interference.
- Considers Statistical characteristics for interference estimation.
- Computed by finding Standard Deviation of Channel Link count for each channel.
- Channel-Link Count for a channel is number of links assigned to that channel.
- A better metric than TID.

TID : A Reliable Metric ?

Expected Correlation Between Metrics & TID

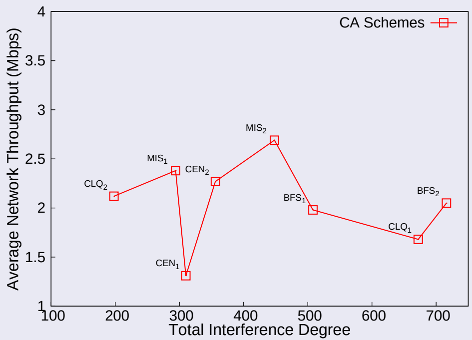




- With increase in TID values
  - Network Throughput should decrease.
  - Loss in data packets should increase.

TID : A Reliable Metric ?

Observed Correlation Between Throughput & TID



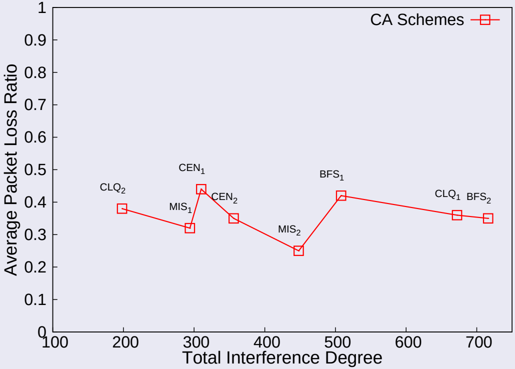
Simulation Parameters

Parameter	Value
Radios/Node	2
Range Of Radios	250 mts
Grid Size	5 * 5
Transmitted File Size	10 MB
Maximum Segment Size (TCP)	1 KB
Packet Size (UDP)	1 KB
MAC Fragmentation Threshold	2200 Bytes
RTS/CTS	Enabled
Packet Interval (UDP)	50ms

- A result from our previous study [2].
  - Labels denote the CA schemes used.
  - Aggregate network throughput of CAs plotted against TID values.

TID : A Reliable Metric ?

Observed Correlation Between PLR & TID



- A result from our previous study [2].
  - Labels denote the CA schemes used.
  - Average Packet Loss Ratio of CAs plotted against TID values.

TID : A Reliable Metric ?

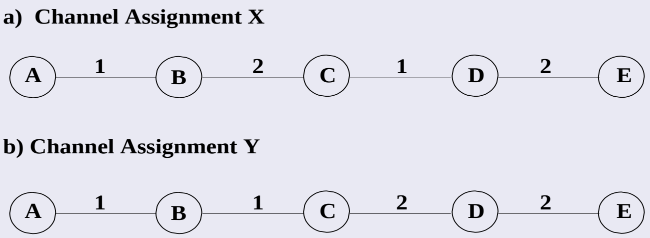
Conclusions

OBSERVED CORRELATION $\nLeftrightarrow$ EXPECTED CORRELATION

- TID $\rightarrow$ Not a reliable metric for interference estimation.
  $\rightarrow$ Not suited to predict CA performance in a WMN.

CDAL_{cost}

Inadequacy of Statistical Interference Estimation



- Interfering links in Fig(a) $\rightarrow$ 0.
- Interfering links in Fig(b) $\rightarrow$ 2.
- CDAL_{cost} for both of them is same $\rightarrow$ 0.

CDAL_{cost}

Conclusions

- CDAL_{cost} $\rightarrow$ Considers Statistical characteristics only.

  $\rightarrow$ Not a perfect metric for interference estimation.

Spatio-Statistical Interference Estimation

Motivation

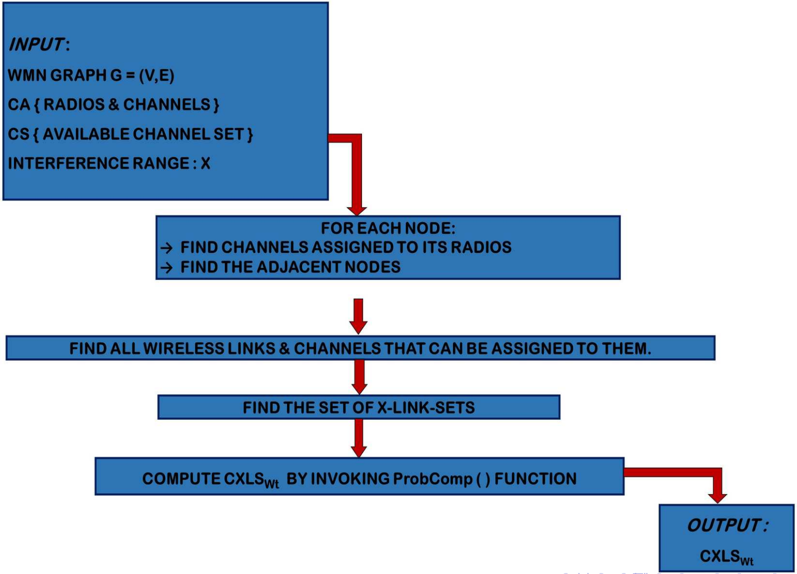
Factors Contributing To Idea Development

- TID and $CDAL_{cost}$ are not reliable metrics.
- Both Statistical and Spatial characteristics should be considered while determining interference.

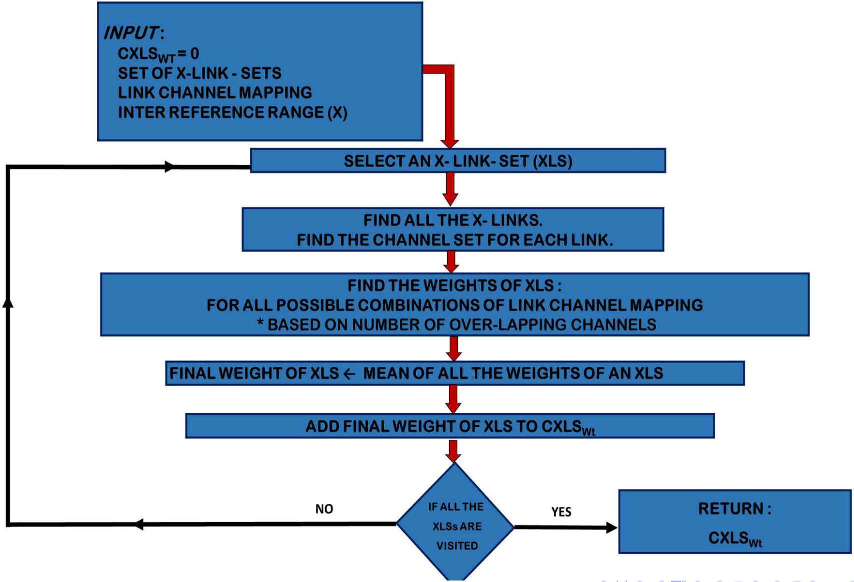
Cumulative X-Link-Set Weight ($CXLS_{wt}$) Approach

- Determines all the XLSs in the WMN.
- XLS is a set of X-consecutive links in the WMN.
- A particular weight is assigned to an XLS based on channels assigned to links in it.

CXLS Algorithm



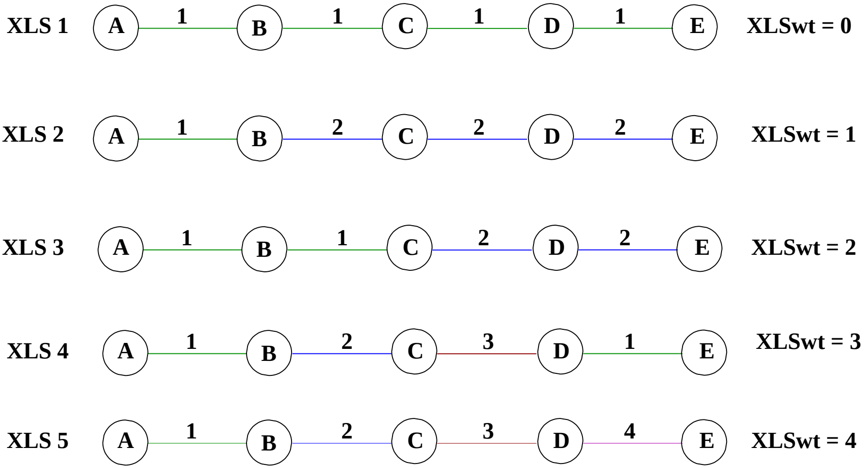
ProbComp() Algorithm



CXLS Algorithm : A Theoretical Illustration

Assigning XLS weights

Interference : Transmission = 4



Test Scenarios & Evaluation Procedure

Simulation Parameters

ns-3 Simulation Parameters

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

Test Scenarios & Evaluation Procedure

Test Scenarios

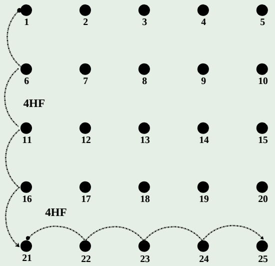
Test Scenarios

- WMN layout $\rightarrow 5 \times 5$ Grid WMN

Grid WMN Test Cases

1. TC5 $\rightarrow$ 5 concurrent 4-Hop flows.
2. TC8 $\rightarrow$ 8 concurrent 4-Hop flows.
3. TC10 $\rightarrow$ 10 concurrent 4-Hop flows.
4. TC12 $\rightarrow$ 12 concurrent flows. (4-Hop & 8-Hop)

Grid WMN Layout



Test Scenarios & Evaluation Procedure

CA Schemes and Representations

CA Schemes Considered

- CLQ-CA [1] → Maximum Clique based CA.
- OIS-CA [2] → Radio Co-location Aware CA.
- EIZM-CA [2] → Radio Co-location Aware CA.
- BFS-CA [3] → Breadth First Search based CA.
- CEN-CA [4] → Centralized Static CA.
- MaIS-CA [5] → Maximum Independent Set based CA.
- GSCA → Grid Specific CA (Minimum TID).

CA Scheme Representation

- E-MMCG and C-MMCG [2] versions of each CA (except GSCA)
  - C-MMCG CA → CA_C, E-MMCG CA → CA_E.
- Representation of CAs
  - BFS-CA (BFS$_C$ & BFS$_E$), MaIS-CA (MIS$_C$ & MIS$_E$).
  - CEN-CA (CEN$_C$ & CEN$_E$), CLQ-CA (CLQ$_C$ & CLQ$_E$).
  - OIS-CA (OIS$_C$ & OIS$_E$), EIZM-CA (EIZM$_C$ & EIZM$_E$).
  - GSCA (GSCA).

Test Scenarios & Evaluation Procedure

Performance Metrics

Observed Network Performance Metrics

- Performance metrics for each test-case
  - Network Throughput.
  - Packet Loss Ratio.
  - Mean Delay.
- For every performance metric $\rightarrow$ Average of all test-cases.
- Performance metrics for each CA
  - Average Network Throughput (Throughput).
  - Average Packet Loss Ratio (PLR).
  - Average Mean Delay (MD).

Test Scenarios & Evaluation Procedure

Evaluation Procedure

CA Sequences From Performance Metrics

- For every performance metric
  - CAs are arranged in increasing order of metric values.

CA Sequences From Theoretical Estimates

- TID, CDAL_{cost}, CXLS_{wt} are computed for each CA.
- CAs arranged in increasing order of **expected performance**.
  - CA Performance $\propto$ 1/ (TID or CDAL_{cost} value).
  - CA Performance $\propto$ (CXLS_{wt} value).
- Increasing order of expected performance is same as the :
  - Decreasing order of TID/CDAL_{cost} values.
  - Increasing order of CXLS_{wt} values.

Test Scenarios & Evaluation Procedure

Evaluation Procedure

Error In Sequence (EIS) Computation

- Sequence of n CAs $\rightarrow$ ${}^{n}C_2$ comparisons.
- CA sequences from experimental metrics $\rightarrow$ Reference.
- In CA sequences from theoretical estimates
  - CA comparisons in error are determined.
  - Prediction by estimation metric contrary to actual performance.
- Sum of all CA comparison errors $\rightarrow$ EIS.

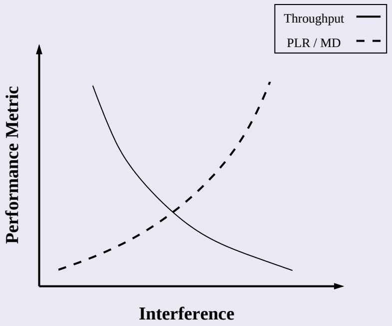
Degree of Confidence (DoC)

- DoC of estimation metric $\rightarrow$ Reliability of CA performance prediction.
- $DoC = (1 - (EIS/{}^{n}C_2)) \times 100$
  - n is the number of CAs in the sequence.

Test Scenarios & Evaluation Procedure

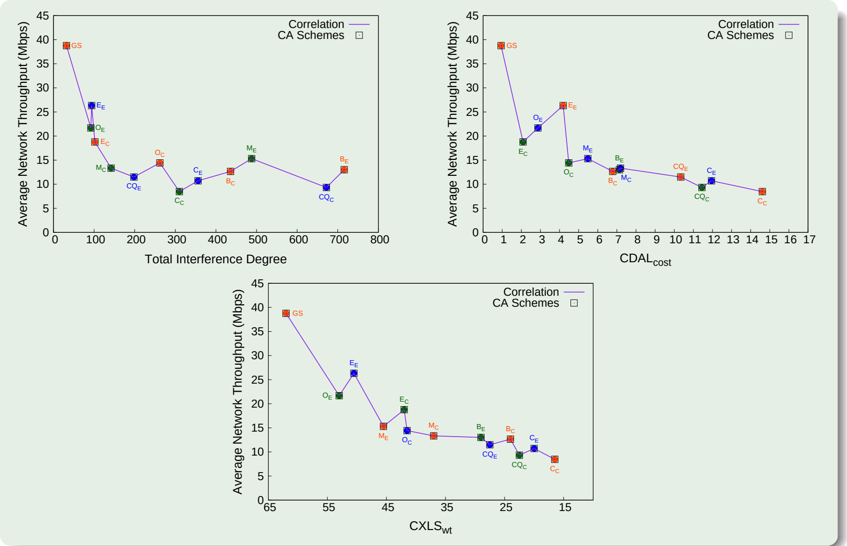
Evaluation Procedure

Expected Correlation Between Metrics & Interference



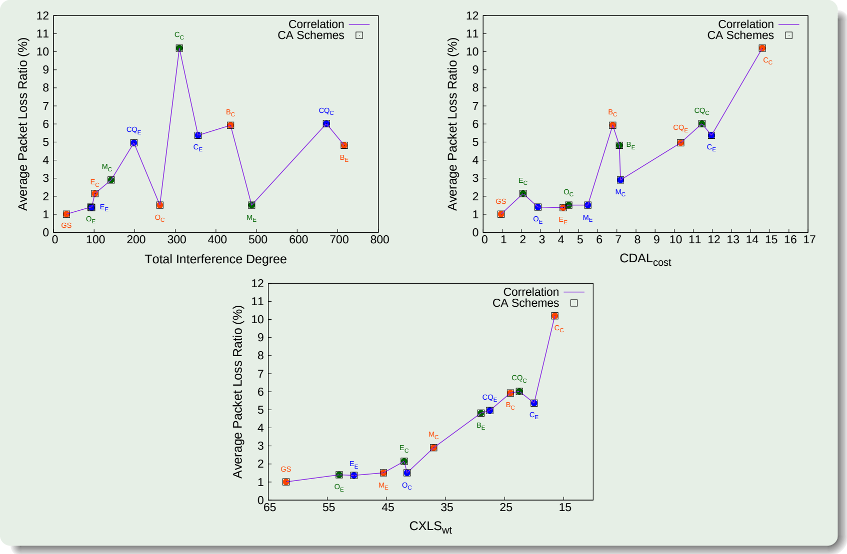
- Plot recorded for CA performance metrics against theoretical estimates.
- Observe the plots for expected correlation.
- Determine DoC for interference estimate accuracy.

$CXLS_{wt}$: Performance Evaluation
Average Throughput



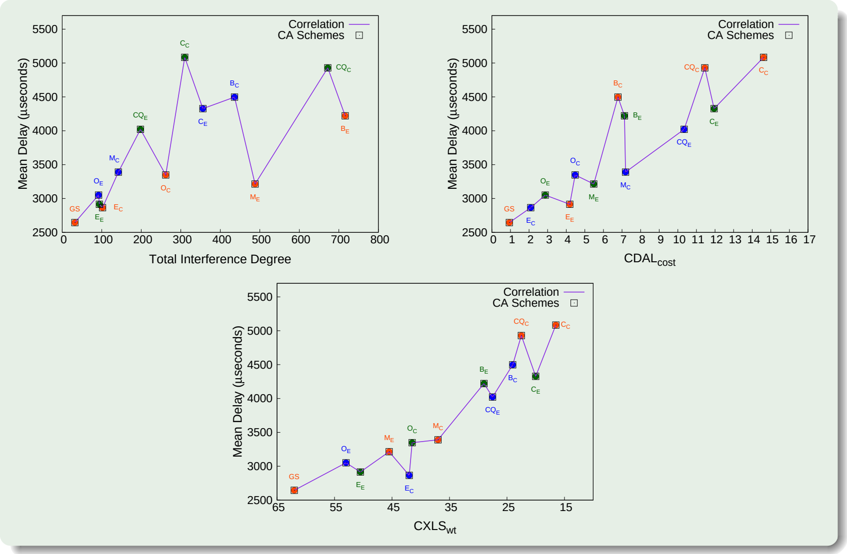
$CXLS_{wt}$: Performance Evaluation

Average PLR



$CXLS_{wt}$: Performance Evaluation

Average MD



Reliability of CXLS$_{wt}$

Degree of Confidence

Performance Metric	Degree of Confidence (%)		
	TID	**CDAL$_{cost}$**	**CXLS$_{wt}$**
Throughput	75.64	89.74	94.87
PLR	75.64	84.61	94.87
MD	76.92	88.46	91.02

Conclusions

CXLS_{wt} Interference Estimation

- Reliable prediction of CA performance.
- Considers both Spatial and Statistical characteristics of interference.
- More accurate than TID and CDAL_{cost}.
- Slightly higher computational cost of O(n^3m^2) compared to TID O(n^2m^3) and CDAL_{cost} O(n^2m^2).
  - $n \rightarrow$ Number of nodes in the WMN.
  - $m \rightarrow$ Number of radios on each node.
- But the overhead of increased algorithmic complexity is compensated by the increase in accuracy levels.

Future Work

- Verify accuracy of CXLS_{wt} in other WMN layouts.
- Use CXLS_{wt} as an optimizing function in CA schemes.
- Devise a prediction estimate based on the individual link quality
  - For quantitative assessment of metrics like Throughput, PLR and MD.

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Thank You

Queries ?