Predicting Performance of Channel Assignments in Wireless Mesh Networks through Statistical Interference Estimation

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Overview

Wirless Mesh Networks (WMNs)

A Promising Technology

- Potential for widespread application.
  - Low-cost availability of IEEE 802.11 hardware.
  - Ease of scalability and reconfigurability.
  - Tremendous increase in data communication rates guaranteed by IEEE 802.11 and IEEE 802.16 standards.
- Wireless technologies that benefit from WMN deployments.
  - IEEE 802.11 WLANs, Wireless Metropolitan Area Networks (WMANs), Cellular mobile systems including LTE-Advanced etc.

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.

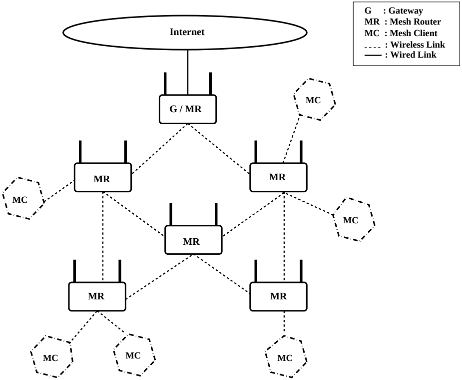


Figure: A Simplistic WMN Architecture

Concepts and Terminology I

Let G = (V, E) represent an arbitrary WMN.
V $\rightarrow$ Set of nodes in G, E $\rightarrow$ Set of wireless links.
Let $i \in V$, $j \in V$, such that $(i, j) \in E$.

Conflict Links

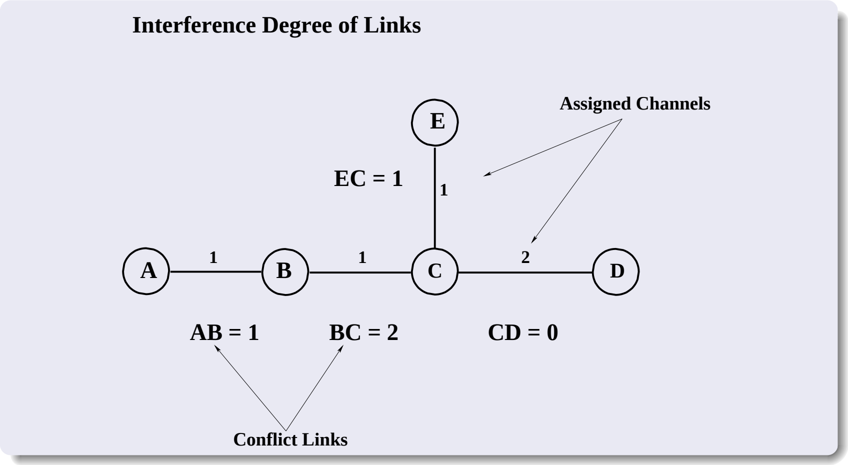
- $\forall (m, n) \in E$, for which the transmitting range of the radio at node m or n, extends upto, or beyond node i or j, are the conflict links of link (i, j).

Interference Degree

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

Concepts and Terminology II

An Illustration



Concepts and Terminology III

Total Interference Degree or TID

- An approximate estimate of the interference prevalent in a WMN.
- Computed by halving the summation of the *Interference Degree* of all the links in G.

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 in WMNs

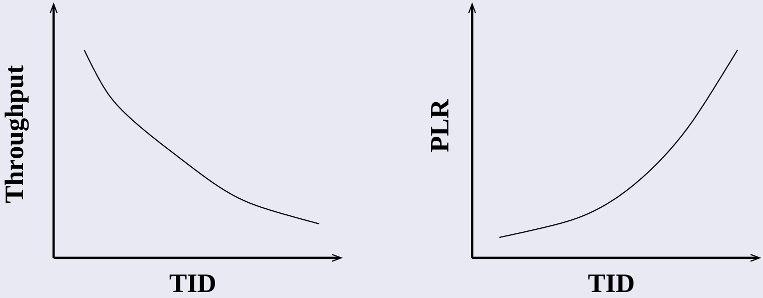
- Interference → Most debilitating factor in network performance.
- Minimizing interference in WMNs is a primary objective.
- Mainly achieved through a prudent channel assignment (CA) scheme, which
  - Enhances network capacity.
  - Reduces end to end latency.
  - Reduces data packet loss.

Selecting the Right CA scheme for a WMN

- Multitude of CA schemes in research literature.
- Choosing an efficient CA for a WMN → A tedious task.
- Absence of CA performance prediction techniques.
- TID → Conventional approach of estimating interference.
    - Considers spatial proximity of links for interference estimation.
    - Not a reliable metric.

TID : A Reliable Metric ?

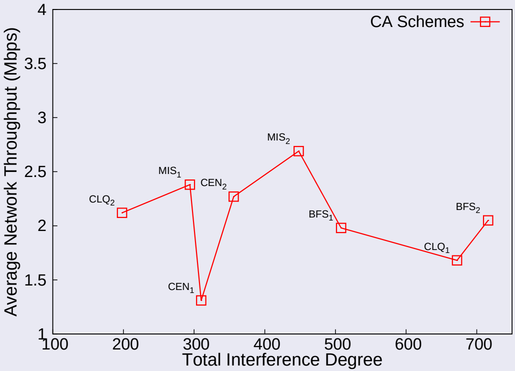
Expected Correlation Between Metrics & TID



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

TID : A Reliable Metric ?

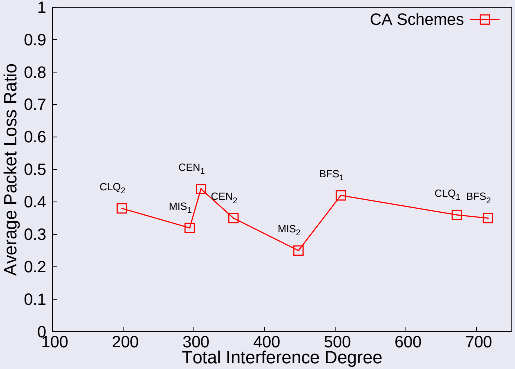
Observed Correlation Between Throughput & TID



- 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.

Fresh Characterization of Interference in WMNs

- We propose a fresh characterization of interference.
- We consider interference to be a three dimensional entity.
- The three dimensions are
    - Temporal
    - Spatial
    - Statistical
- We employ this model for interference estimation.

The Three Dimensions of Interference

Temporal Characteristics

- Data transmissions in Wireless network → Not synchronized
  → Random.
- Interference complexities → Function of time
  → Fundamentally temporal.

Spatial Characteristics

- Link Conflicts → Spatial proximity && Identical channel.
- Spatial interaction of wireless links → Interference in WMNs.

The Three Dimensions of Interference

Statistical Characteristics

- Channel assignment to radios → Complexity of interference.
- Even distribution of channels among radios → Fewer wireless conflicts.

Statistical Interference Estimation

Motivation

Factors Contributing To Idea Development

- TID is not a reliable metric.
- Statistical distribution of channels is linked to CA performance.

Proposed Approach

- **Channel Distribution Across Links** (CDAL) Approach.
- Determines distribution of channels across links.
- Computes $\text{CDAL}_{cost} \rightarrow$ Interference estimate.

Features of CDAL Approach

Probabilistic Selection of Links

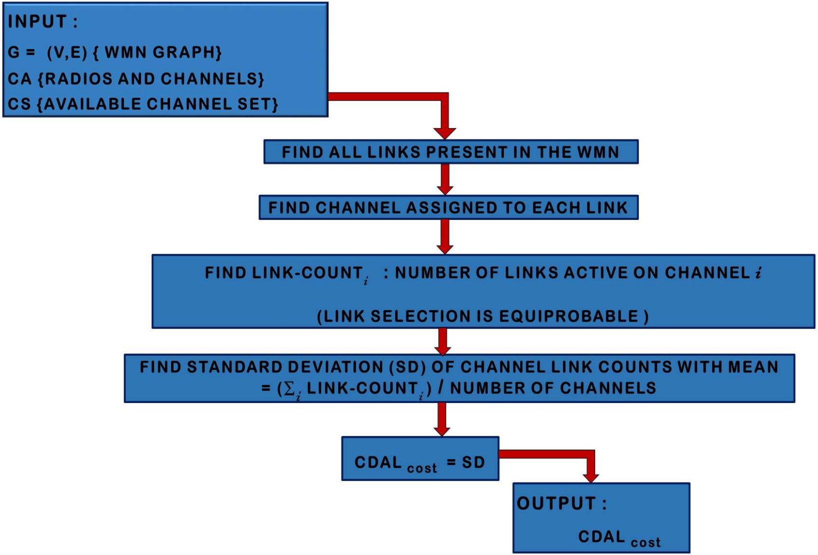
- Transmission link selection is dynamic/temporal.
  - Happens at the MAC layer.
  - Predicting link selected for a transmission is difficult.
- Multiple links exist between two nodes.
  - Each link is considered equally likely to be selected.

An Example

(i) Network Topology (ii) Available Communication Channels

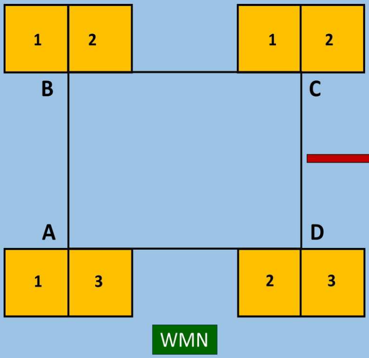
- A & C can communicate on Channel_1 or Channel_2.
- CDAL considers both links equally likely.

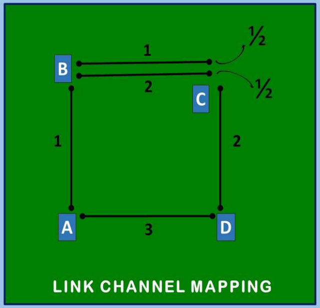
CDAL Algorithm



CDAL Algorithm : A Theoretical Illustration

Sample WMN 1



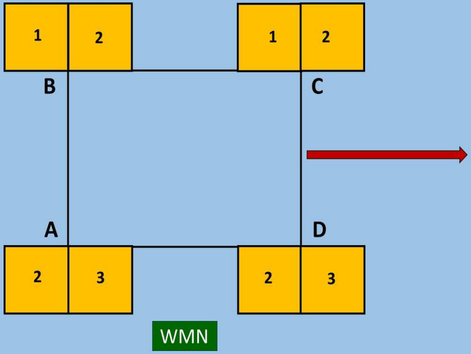


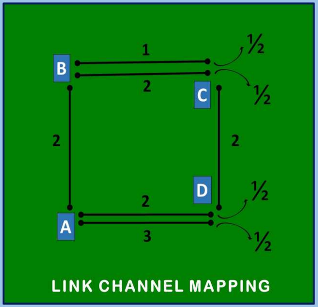
$Ch_1 : Ch_2 : Ch_3 \rightarrow 1.5 : 1.5 : 1$

$CDAL_{COST} = 0.2357$

CDAL Algorithm : A Theoretical Illustration

Sample WMN 2





$Ch_1 : Ch_2 : Ch_3 \rightarrow 0.5 : 3 : 0.5$

$CDAL_{COST} = 1.1785$

Choice of CA Schemes

CA Schemes Considered

- BFS-CA [3] → Breadth First Search based CA.
- MaIS-CA [5] → Maximum Independent Set based CA.
- CLQ-CA [1] → Maximum Clique based CA.
- CEN-CA [4] → Centralized Static 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$_E$).
  - GSCA (GSCA).

Test Scenarios & Evaluation Procedure

Test Scenarios

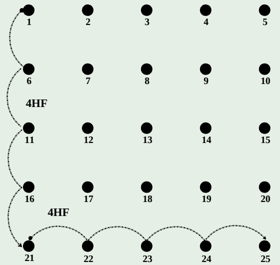
Test Scenarios

- WMN layout → 5×5 Grid WMN

Grid WMN Test Cases

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

Grid WMN Layout



Test Scenarios & Evaluation Procedure

Performance Metrics

Observed Network Performance Metrics

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

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

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 and $CDAL_{cost}$ are computed for each CA.
- CAs arranged in increasing order of **expected performance**.
  - CA Performance $\propto$ 1/ (TID or $CDAL_{cost}$ value).
- Increasing order of expected performance $\rightarrow$
  Decreasing order of TID/ $CDAL_{cost}$ 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.

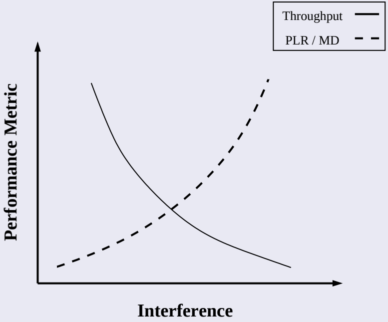
Degree of Confidence (DoC)

- 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

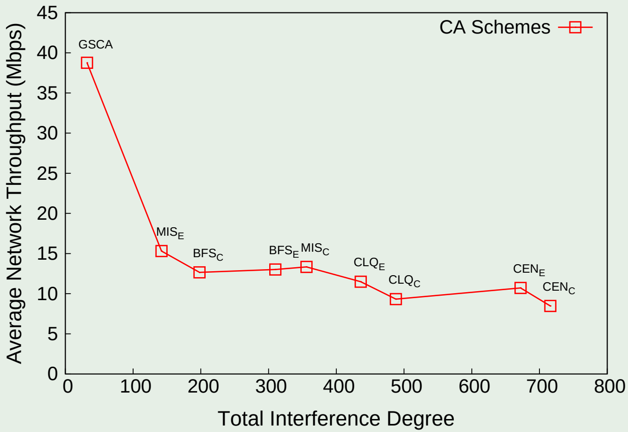
Expected Correlation Between Metrics & TID



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

CDAL_{cost} : Performance Evaluation

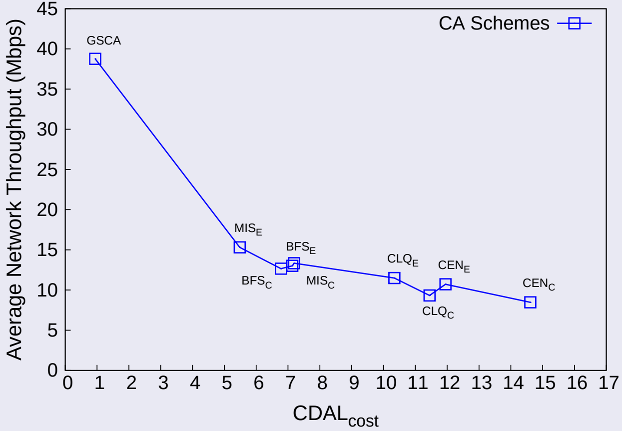
Avg Throughput vs TID Estimates



- Throughput does not decrease consistently with increase in TID.

CDAL_{cost} : Performance Evaluation

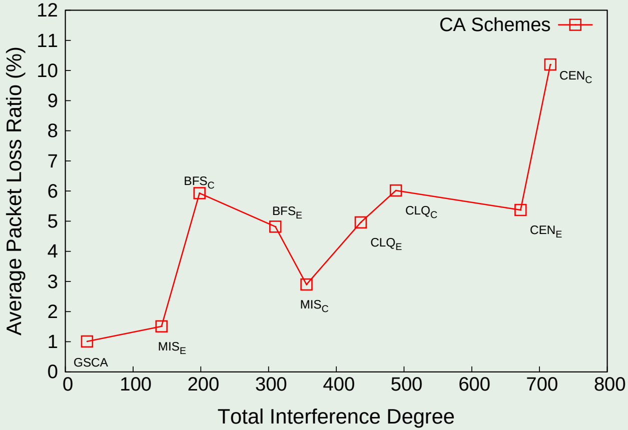
Avg Throughput vs CDAL_{cost}



- More consistent decrease in Throughput with increase in CDAL_{cost}.

$CDAL_{cost}$: Performance Evaluation

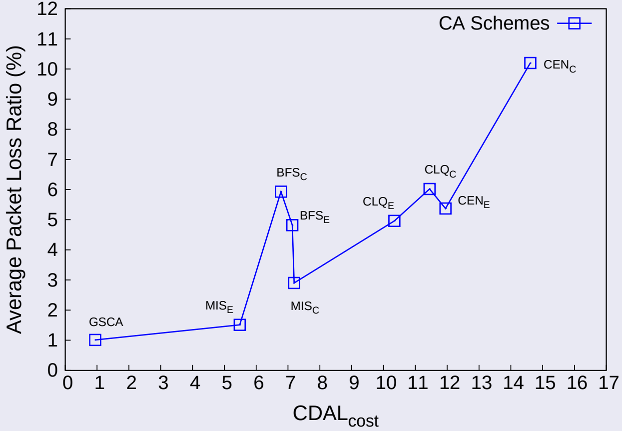
Avg PLR vs TID Estimates



- High deviation from expected correlation.

$CDAL_{cost}$: Performance Evaluation

Avg PLR vs $CDAL_{cost}$



- Lesser deviation from expected correlation.

Reliability of CDAL$_{cost}$

Degree of Confidence

Performance Metric	TID		CDAL$_{cost}$	
	EIS	DoC (%)	EIS	DoC (%)
Avg Throughput	15	58.33	4	88.89
Avg PLR	12	66.67	7	80.55

Conclusions

CDAL_{cost} Interference Estimation

- Reliable prediction of CA performance.
- More accurate than TID.
- Lesser computational cost O(n^2m^2) than TID O(n^2m^3).
  - $n \rightarrow$ Number of nodes in the WMN.
  - $m \rightarrow$ Number of radios on each node.

Future Work

- Verify accuracy of CDAL_{cost} in other WMN layouts.
- Devise a better metric than CDAL_{cost} through.
  - Spatio-statistical accounting of interference.
  - Link-quality based interference estimation.
- Use CDAL_{cost} as an optimizing function in CA schemes.

References I

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THANK YOU

QUERIES ?