Quantized Conflict Graphs for Wireless Networks Optimization

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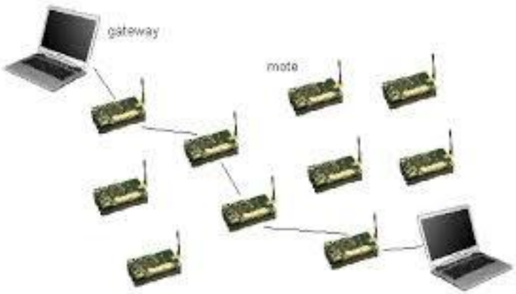
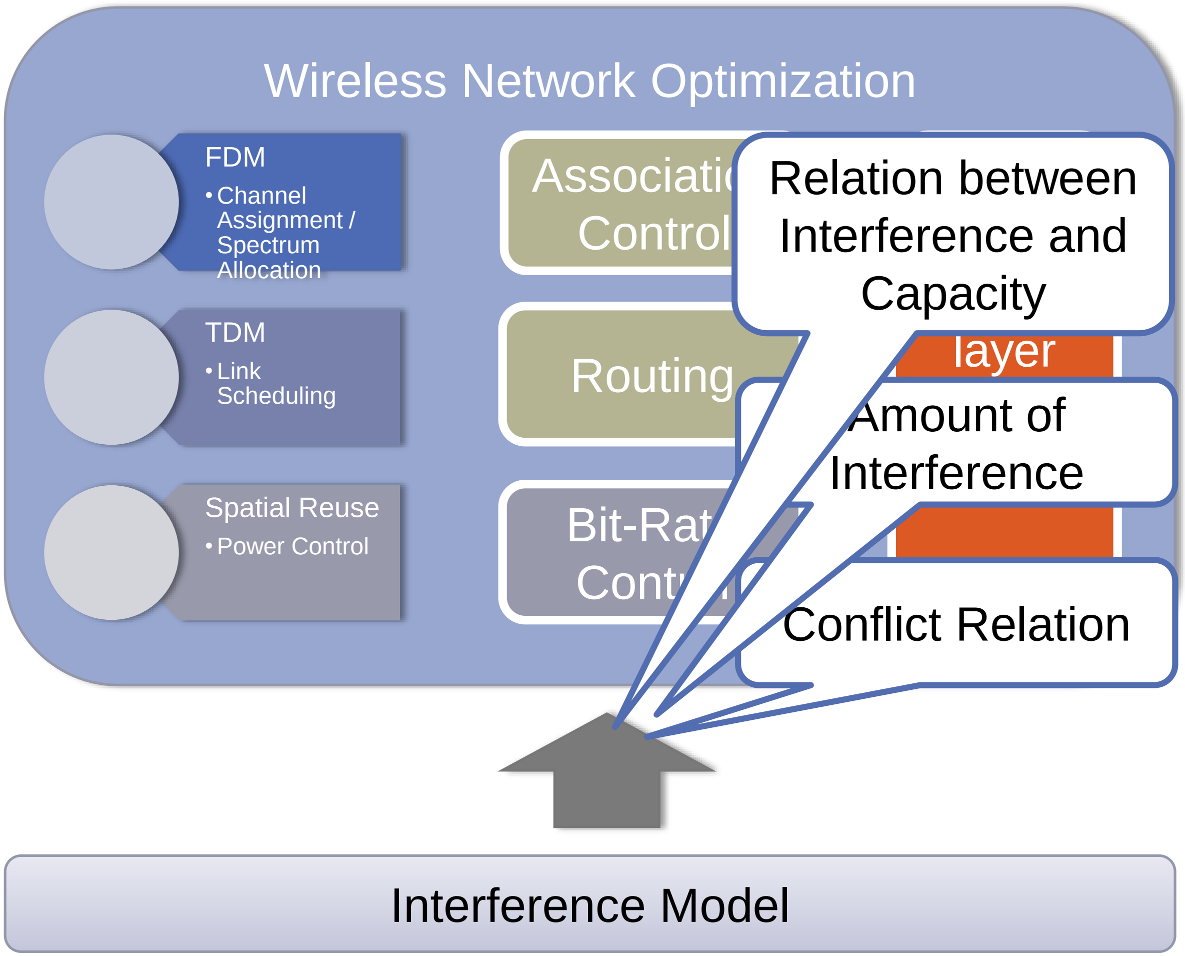
Background

- Wireless Networks are Ubiquitous
  - WiFi
  - 3G/4G Network
  - Wireless Sensor Network
  - Wireless Mesh Network



- Wireless Medium is shared
  - The number of channels is limited
  - The bandwidth of channels is limited
  - Spatial Reuse is conflict with Coverage range

Interference Model for Wireless Network Optimization



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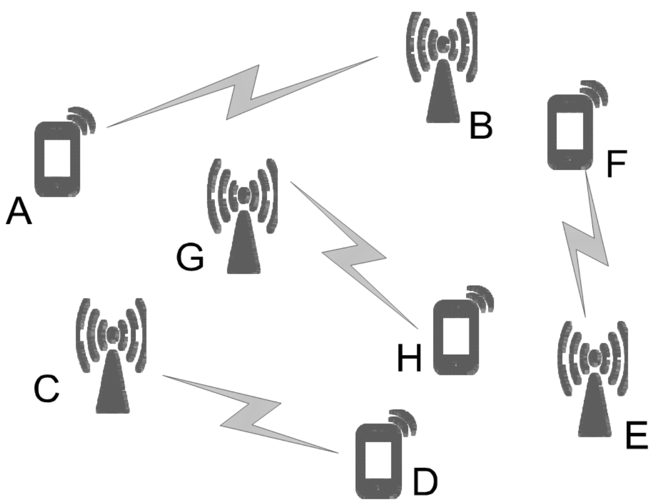
WHY DO WE NEED A NEW MODEL

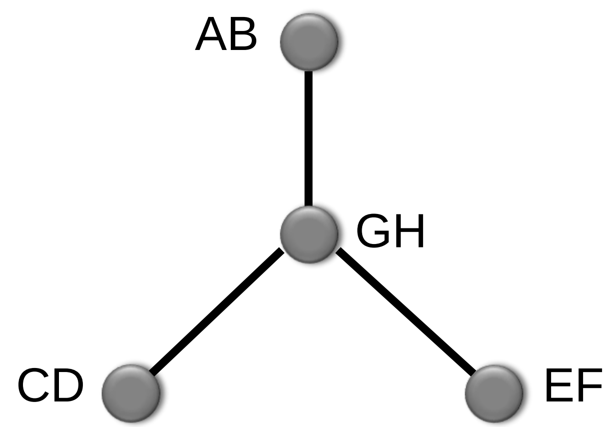
Physical Interference Model (SINR Model)	Accurate	Exhausting Measurement	Non-convex
A Quantized Conflict Graph Model	Finer-grained	Partial Measurement	Classic Graph Algorithm
Protocol Interference Model (Conflict Graph)	Coarse-grained	Accumulative Interference	Classic Graph Algorithm

Motivation Example

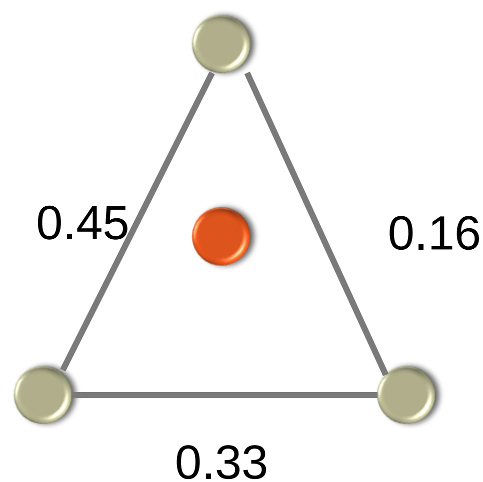


RSS Measurement

Link pairs	RSS(μW)
AB,GH	0.55
CD,GH	0.65
EF,GH	0.92
AB,CD	0.45
CD,EF	0.33
AB,EF	0.16
Rest	<0.10

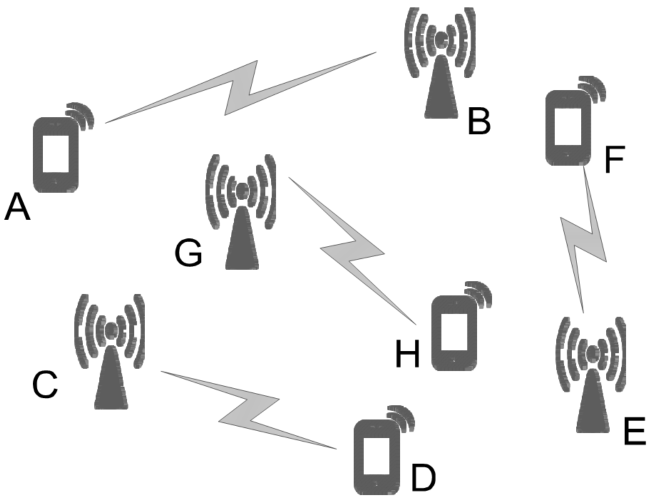


Traditional conflict graph



Total Interference : 0.94

Motivation Example



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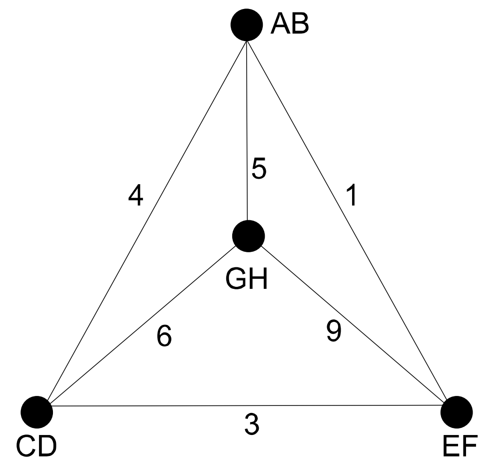
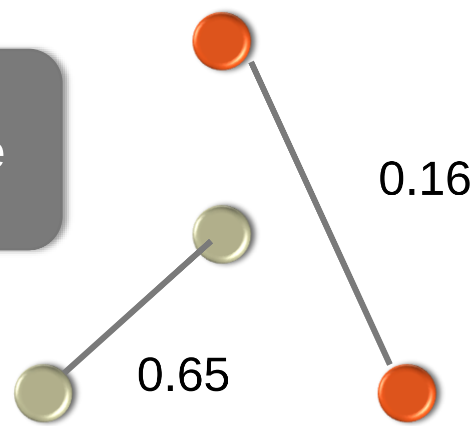


Total Interference : 0.81



QCG Definition

Quantized
Conflict Graph

Pros

- Do not require an accurate RSS to get the same allocation Results
- Rough RSS representation could increase the prediction accuracy

We apply a Step function

$$f(x) = \lfloor \frac{x \times M}{C_{max}} \rfloor$$

to map the RSS to the M-level weights in the graph

Properties of QCG

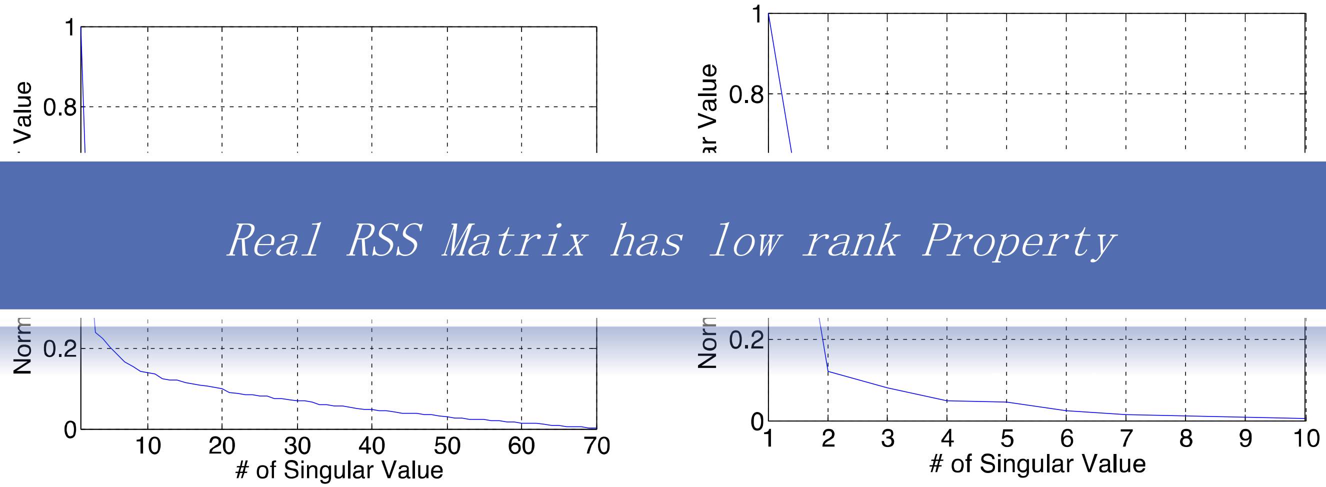
Exhaustive signal measurements at outdoor/indoor WiFi networks

Dataset	In/out	Area (km^2)	#of APs	Avg # of APs heard per location	# of measured locations
MetroFi	Outdoor	7	70	2.3	30,991
SWIM Platform	Indoor	<1	10	5	40

- Transformed into Quantized RSS Matrix

Properties of QCG

- Explore the low-rank Property

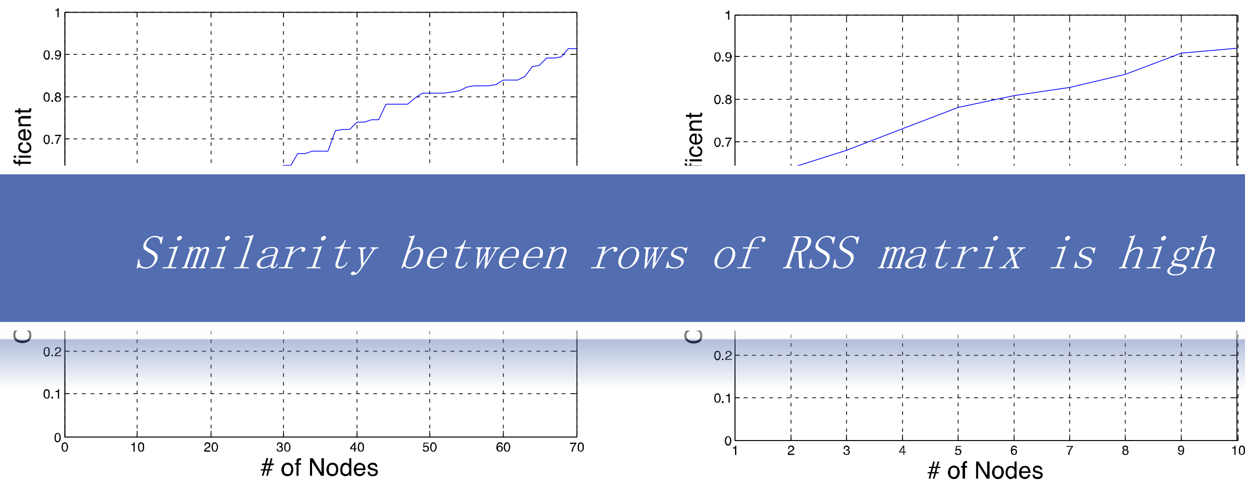


Real RSS Matrix has low rank Property

(a) MetroFi dataset. (b) SWIM dataset.

Properties of QCG

- Explore the similarity between rows



(a) MetroFi dataset. (b) SWIM dataset.

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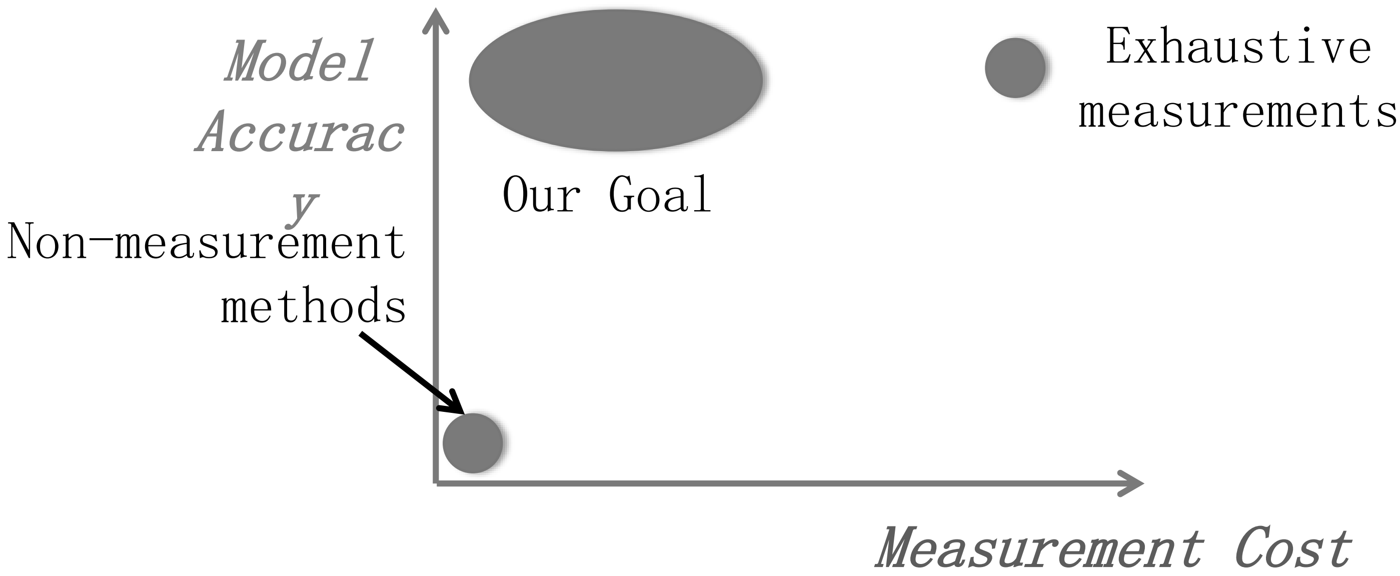
Efficient QCG Estimation



Our approach: *measure a few, predict many*

Efficient QCG Estimation

- **Basic Idea**

Quantized Conflict Graph →

$$X = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,N} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ x_{N,1} & x_{N,2} & \cdots & x_{N,N} \end{bmatrix}$$

Utilize the Properties of *Quantized RSS Matrix*

Treat Quantized RSS prediction as a ***Matrix Completion Problem***

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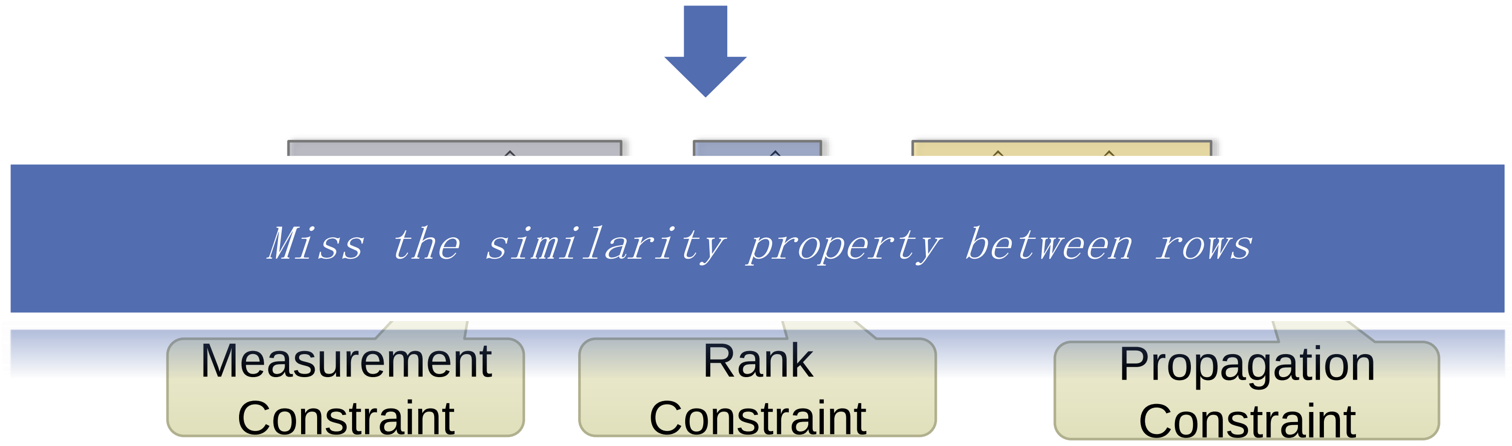
Efficient QCG Estimation

- Low-rank Approximation

$$
\begin{aligned}
\min_{\hat{X}} \quad & rank(\hat{X}) \\
s.t. \quad & \hat{x}_{ij} = x_{ij}, \quad (i,j) \in \Omega \\
& \hat{x}_{ij} \in \mathcal{C},
\end{aligned}
$$



Efficient QCG Estimation

- Similarity
  - $$r_{ij} = \frac{\sum_{l=1}^{N}(X_{il} - \bar{X}_i)(X_{jl} - \bar{X}_j)}{\sqrt{\sum_{l=1}^{N}(X_{il} - \bar{X}_i)^2}\sqrt{\sum_{l=1}^{N}(X_{jl} - \bar{X}_j)^2}}$$
  - We applied the idea of k-nearest neighbor here

$$\hat{x}_{ij} = \frac{\sum_{k \in N(i,j)}(S(k,j)x_{kj})}{\sum_{k \in N(i,j)} S(k,j)}.$$

Good to deal with the Matrix with small portion of Missing Elements

Efficient QCG Estimation

- Comprehensive
  - Trivial to combine the similarity and low-rank approximation together and improve the accuracy

Use the low-rank approximation to compute a matrix X

Compute the Similarity between rows in X

Apply the linear regression for k-largest similar rows to compute weights

Compute un-known entries with the weights computed in last step

QCG-BASED OPTIMIZATION

Interference Minimization

Definition
- K channels, N nodes(links)
- Minimize the total network interference

→ **Max K-cut Problem**

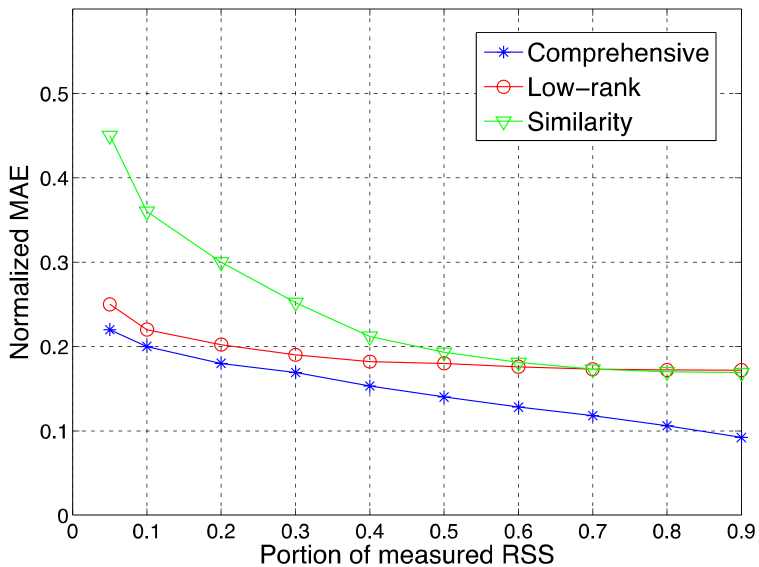
Scheduling

Definition
- K channels, N nodes(links)
- Minimize the total network interference

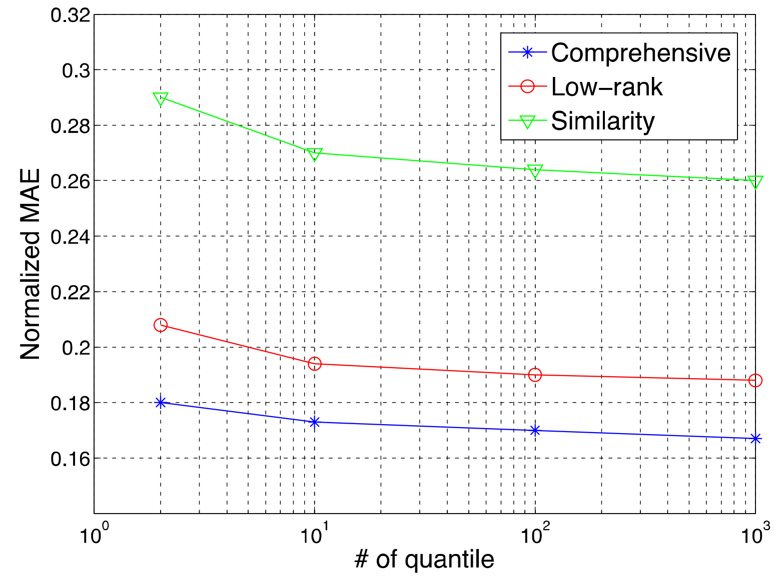
→ **Max Weighted Independent Set**

Evaluation

- Prediction Accuracy



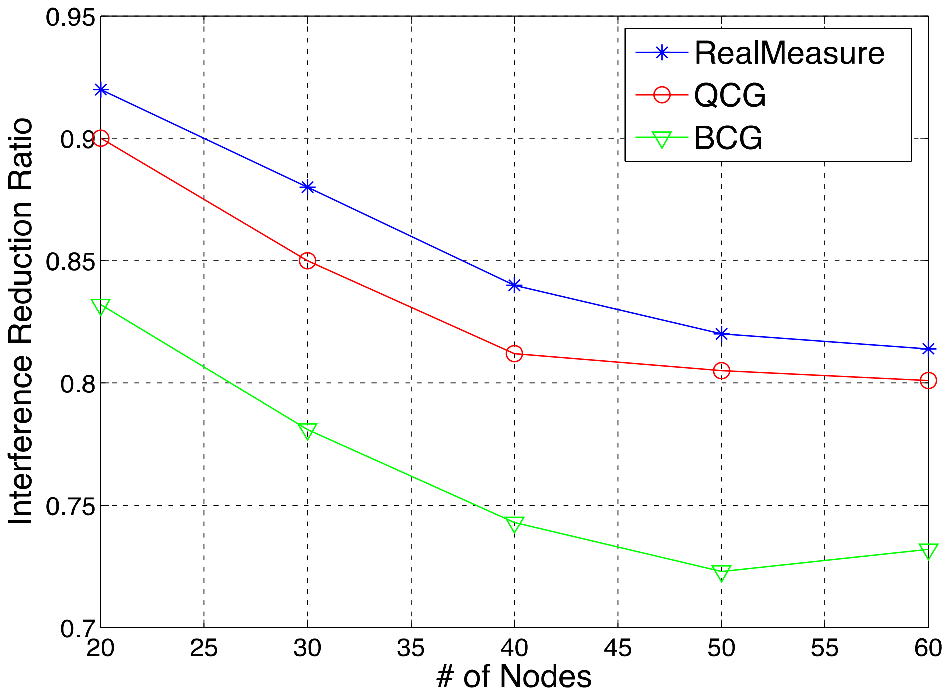
Comprehensive Method perform best with the others mutually complementary



Increase the number of levels larger than 10 only slightly improve the accuracy

Evaluation

- Wireless Network Optimization



Thanks