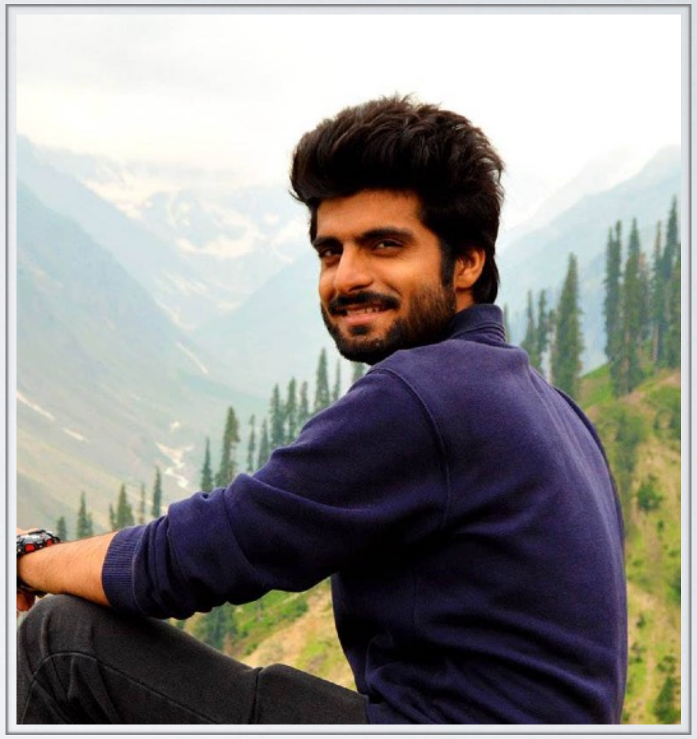
PREDICTING END-TO-END CAPACITY OF PLC-WIFI PATHS

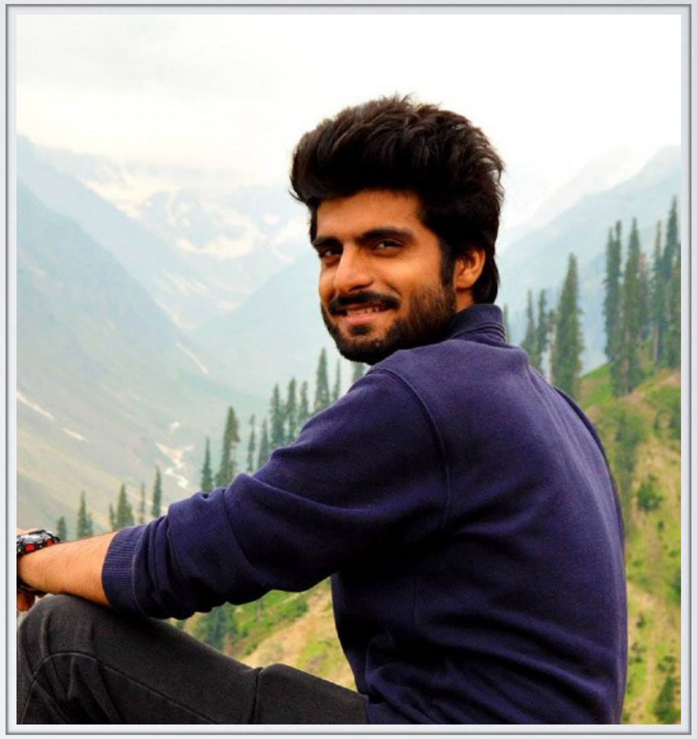
Khurram Javed
Supervisors : Victor Kristof and Sébastien Henri

INTRODUCTION

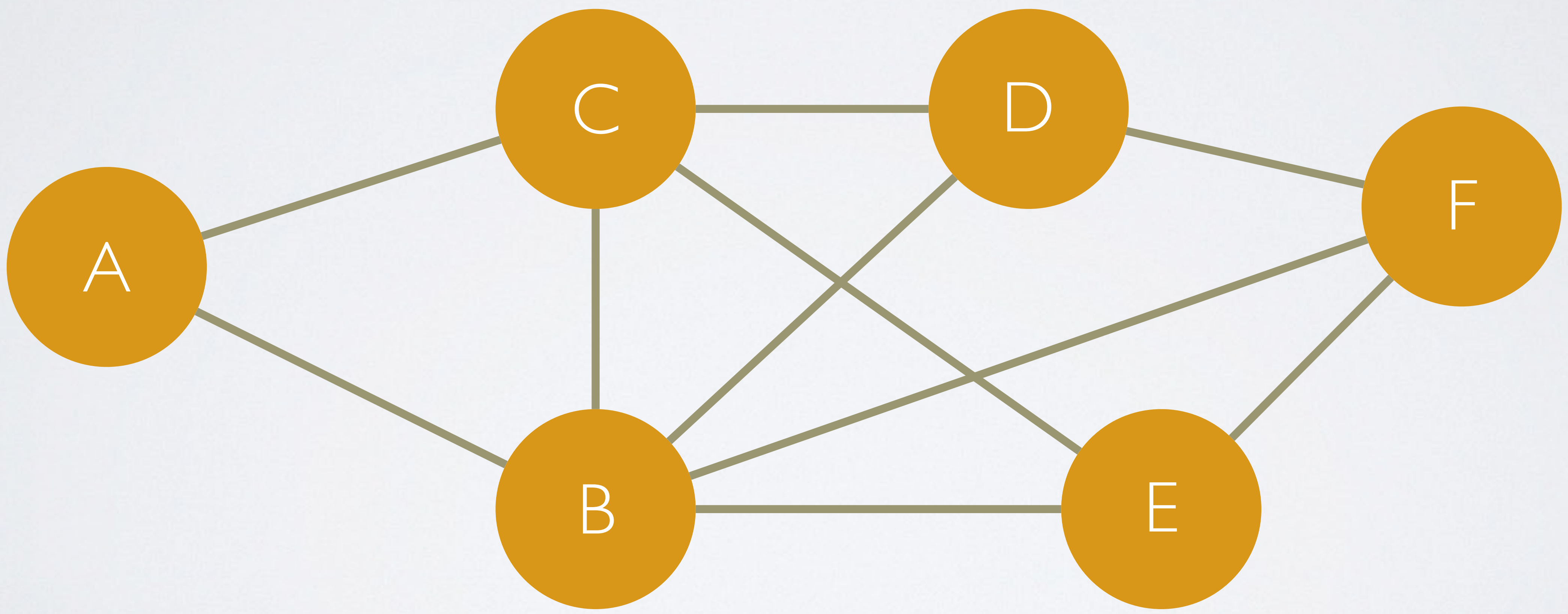


INTRODUCTION

- 4th Year Student of BS Comp Sci, NUST.
- From Islamabad, Pakistan
- Hopes and dreams of becoming a researcher in CS/AI.
- Working at LCA3 for 3 months.

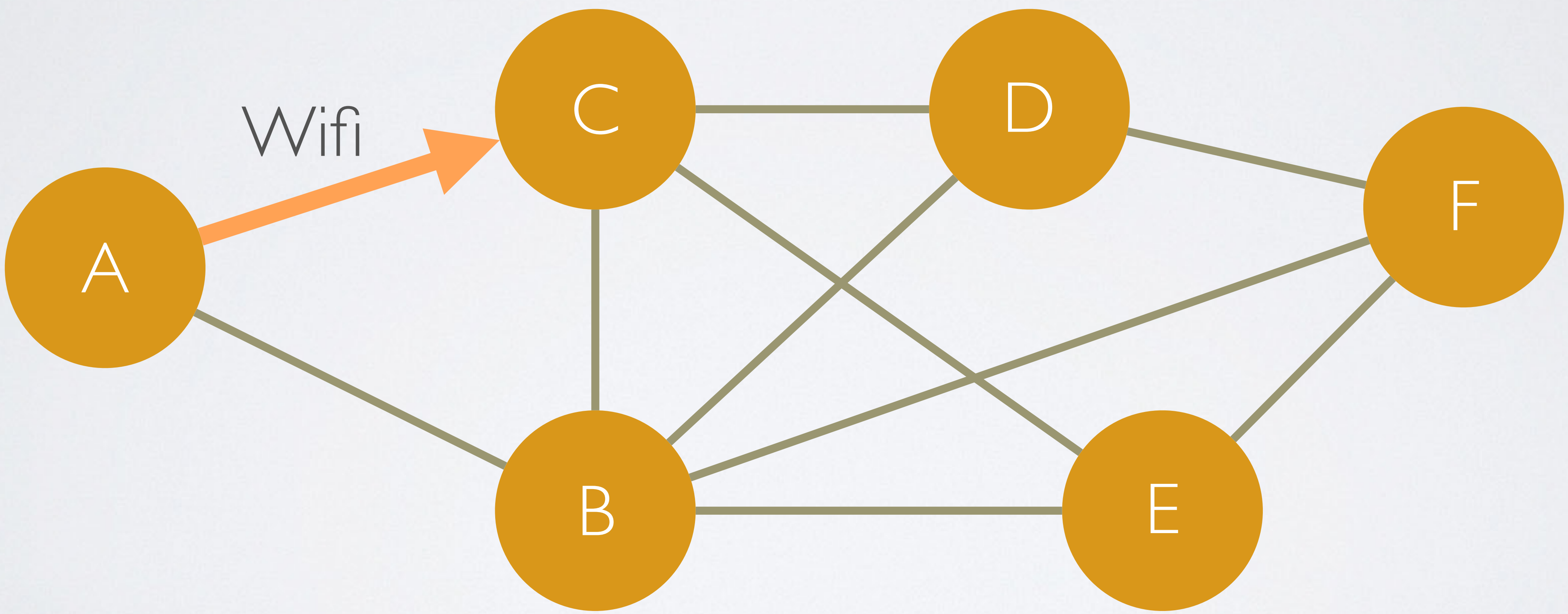


INSPIRATION



Ad-Hoc Network

INSPIRATION



Ad-Hoc Network

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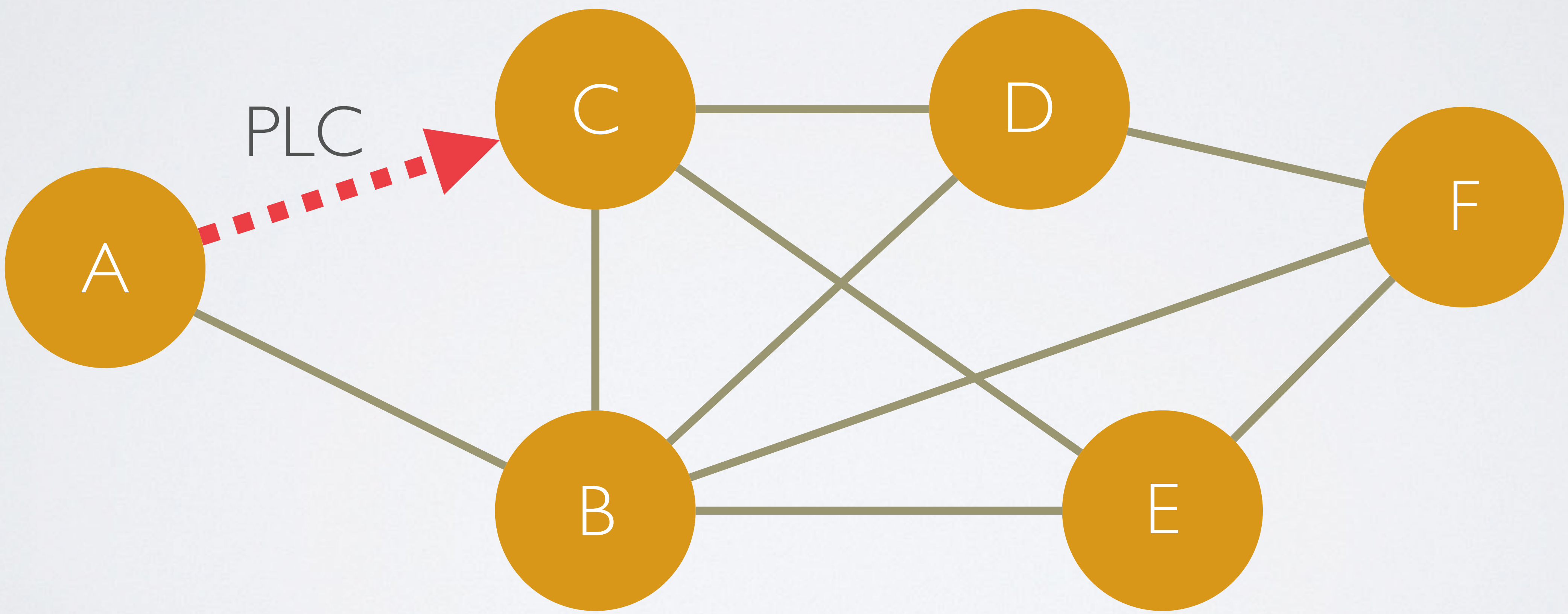
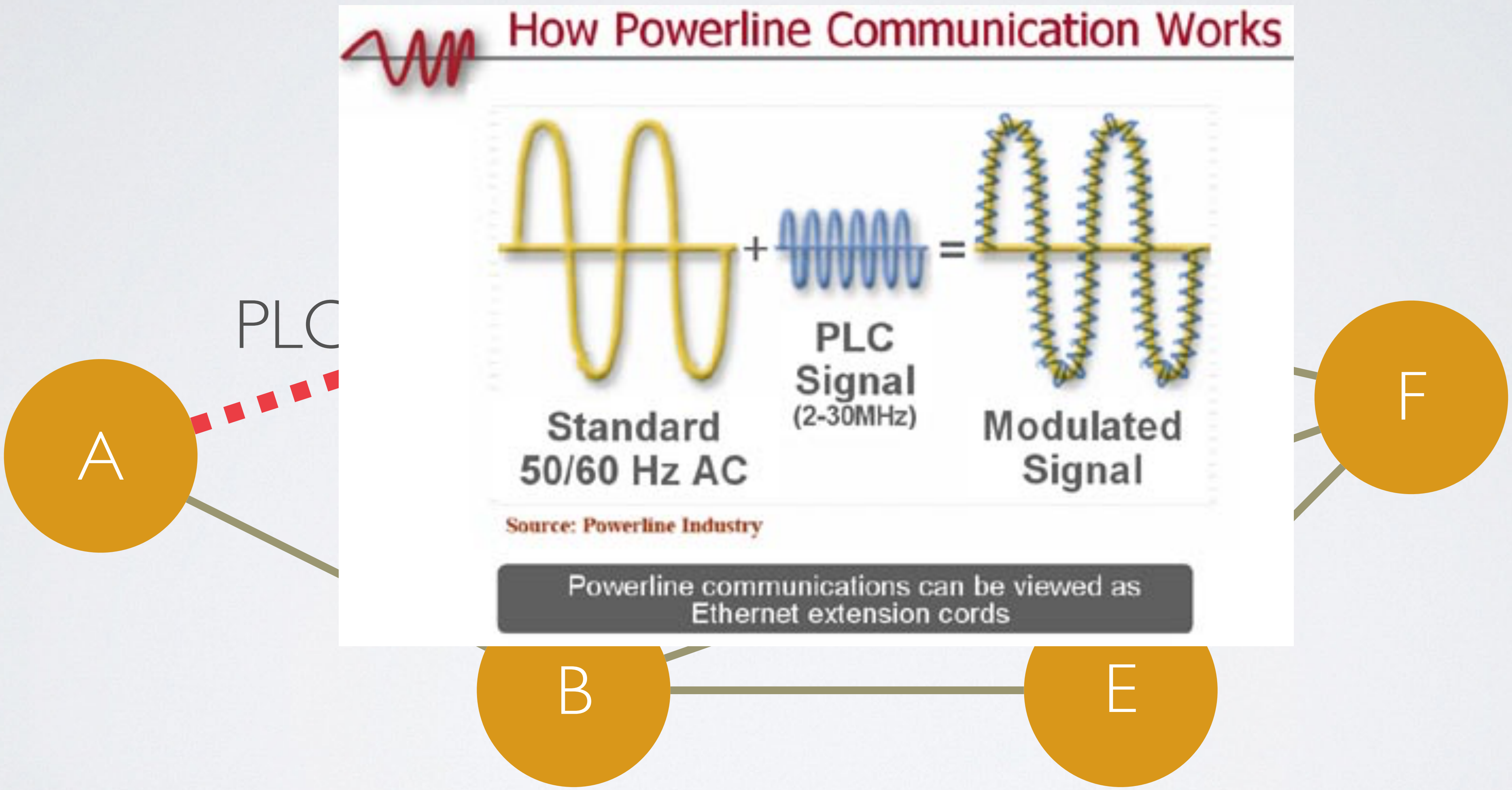


Ad-Hoc Network

INSPIRATION

PLC : Power line communication

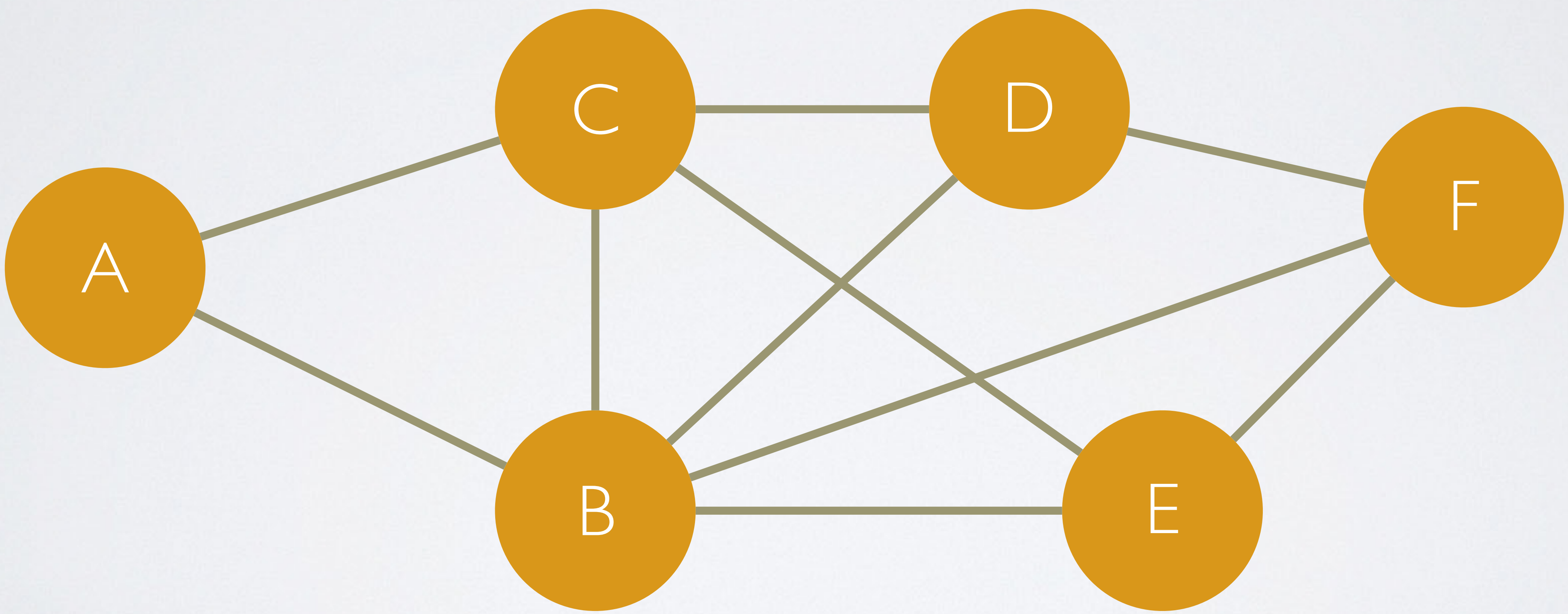


Reference : https://hsto.org/storage2/086/593/3be/0865933be400e79397b51ca543b88057.jpg

Ad-Hoc Network

INSPIRATION

GOAL : Transmit data from A to F

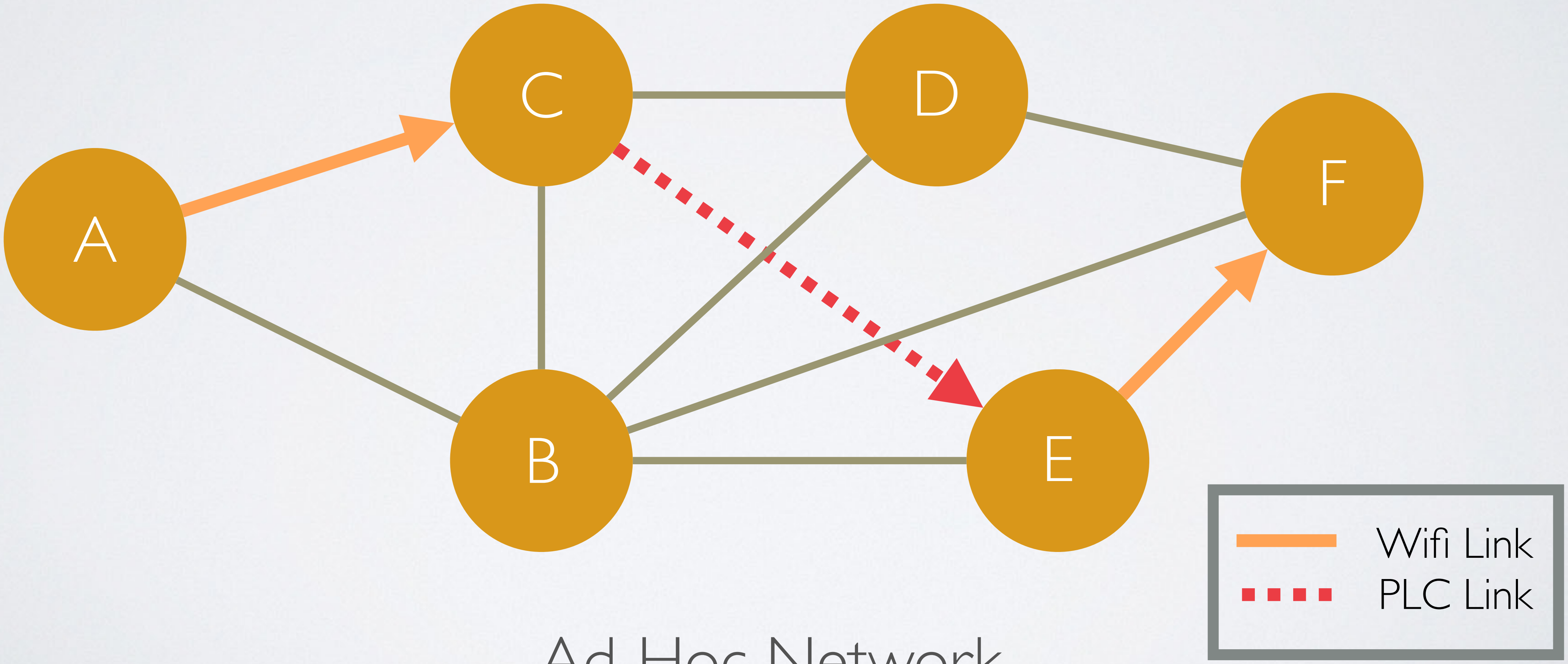


Ad-Hoc Network

INSPIRATION

GOAL : Transmit data from A to F

Possibility 1 : $A_W C_P E_W F$

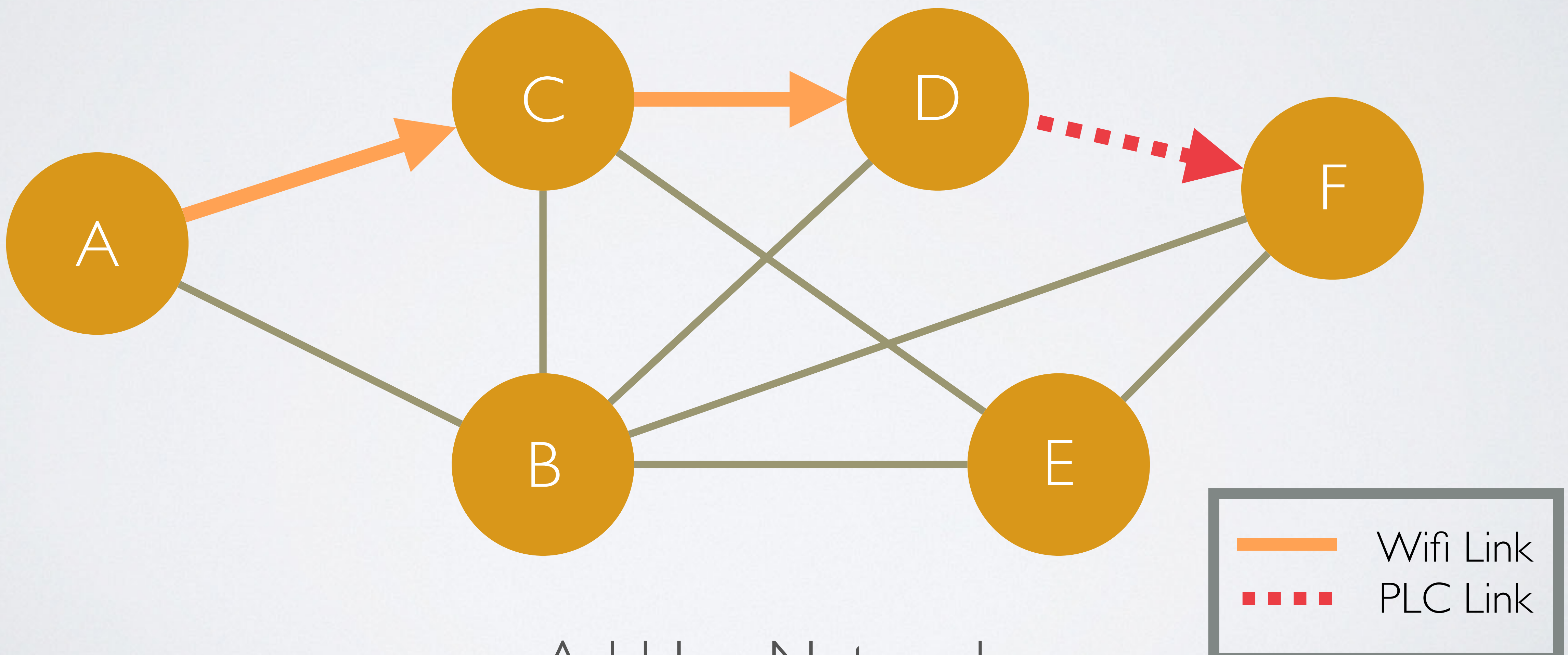


Ad-Hoc Network

INSPIRATION

GOAL : Transmit data from A to F

Possibility 2 : $A_W C_W D_P F$

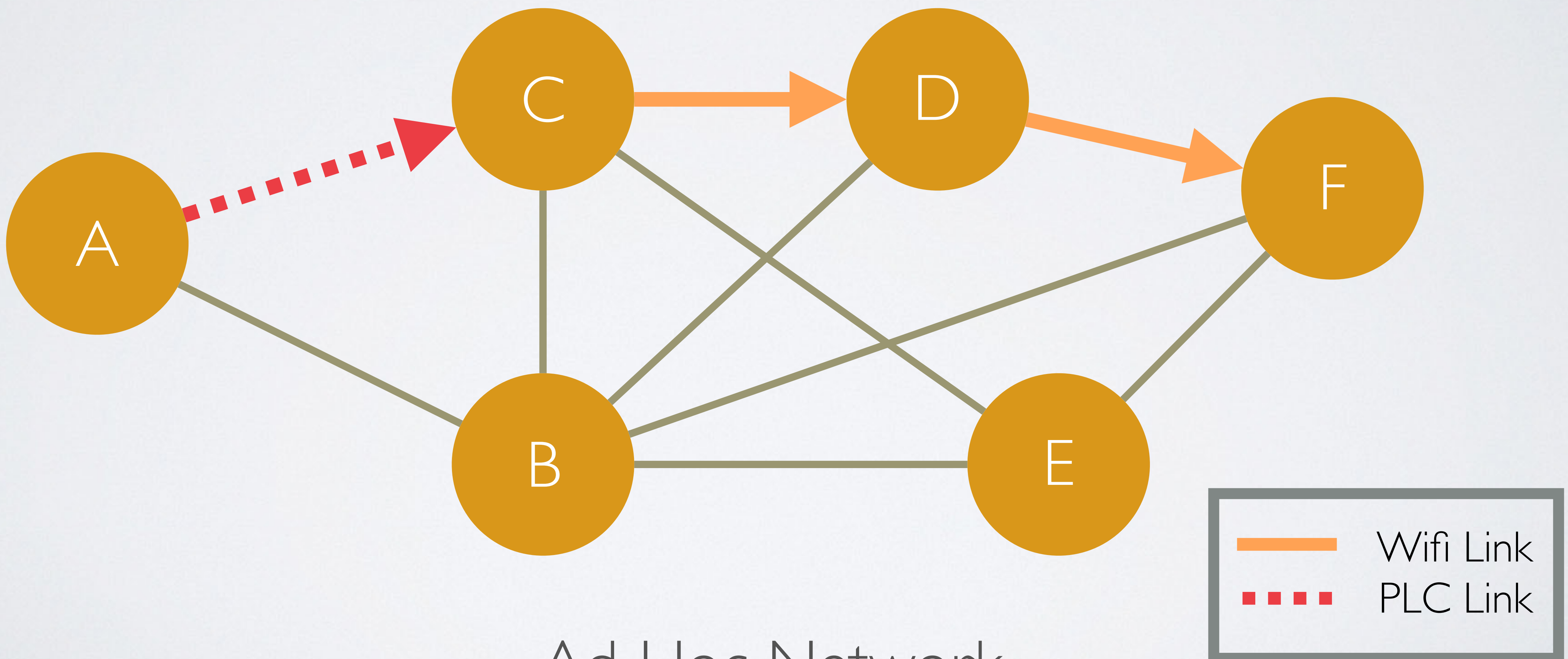


Ad-Hoc Network

INSPIRATION

GOAL : Transmit data from A to F

Possibility 3: $A_pC_wD_wF$

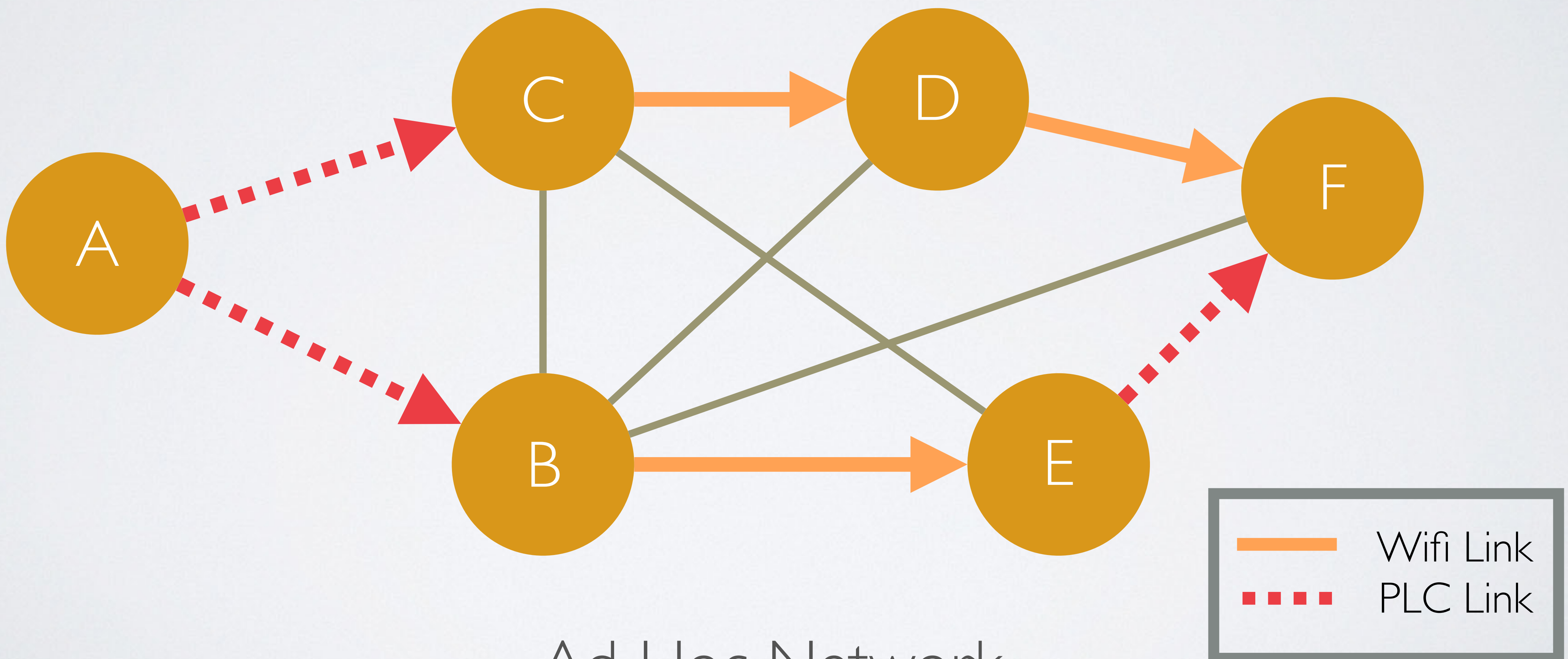


Ad-Hoc Network

INSPIRATION

GOAL : Transmit data from A to F

Possibility 4: $A_pC_wD_wF$
and $A_pB_wE_pF$



Ad-Hoc Network

INSPIRATION

Multiple options!

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Multiple options!

How do we decide which one is the best?

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How do we decide which one is the best?

Answer : Pick to maximize capacity!

PROBLEM STATEMENT

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"Predict end-to-end capacity of PLC-Wifi paths."

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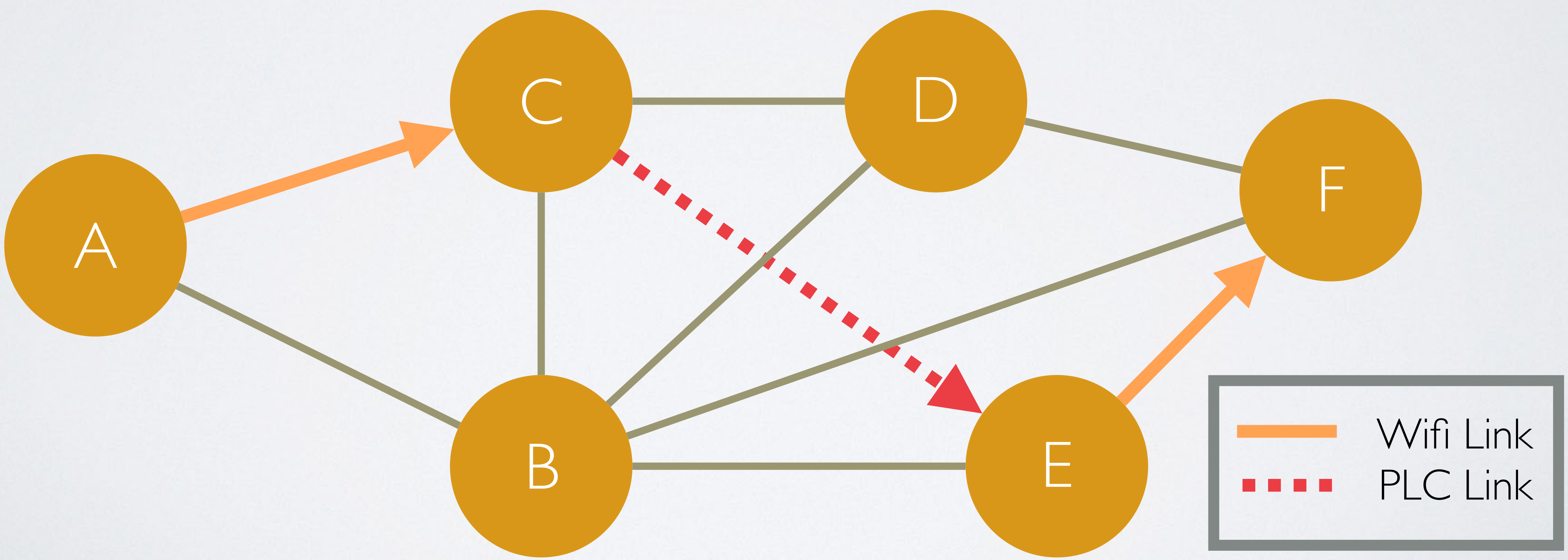
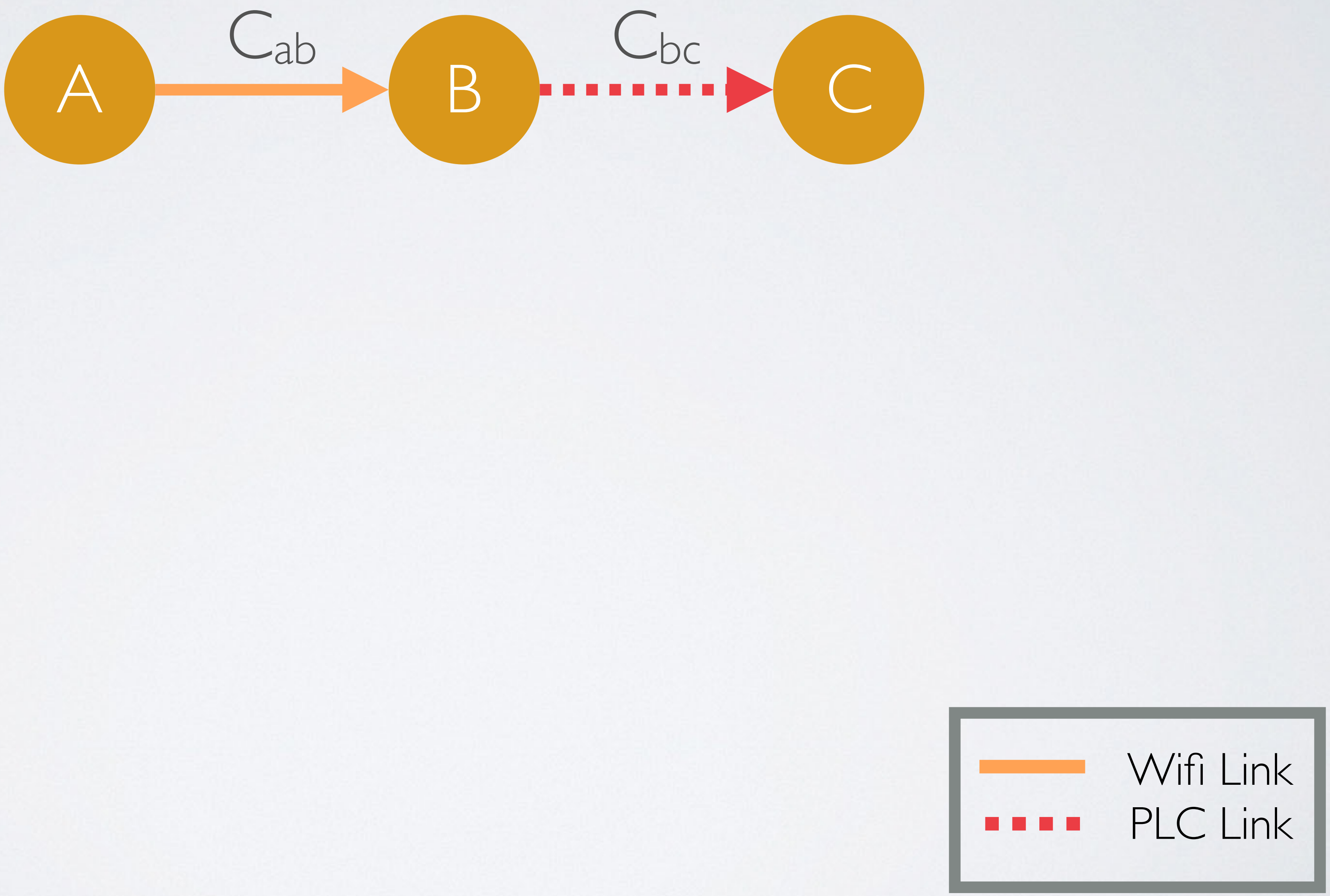
"Predict end-to-end capacity of PLC-Wifi paths."

What is the capacity of $A_W C_P E_W F$?



EXISTING SOLUTION



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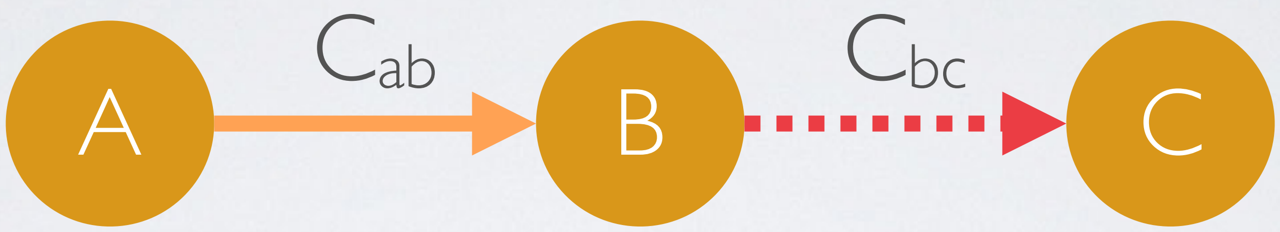
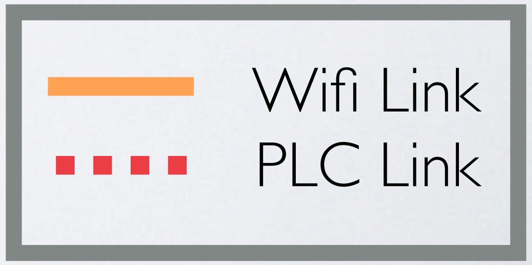


$$min(C_{ab}, C_{bc})$$



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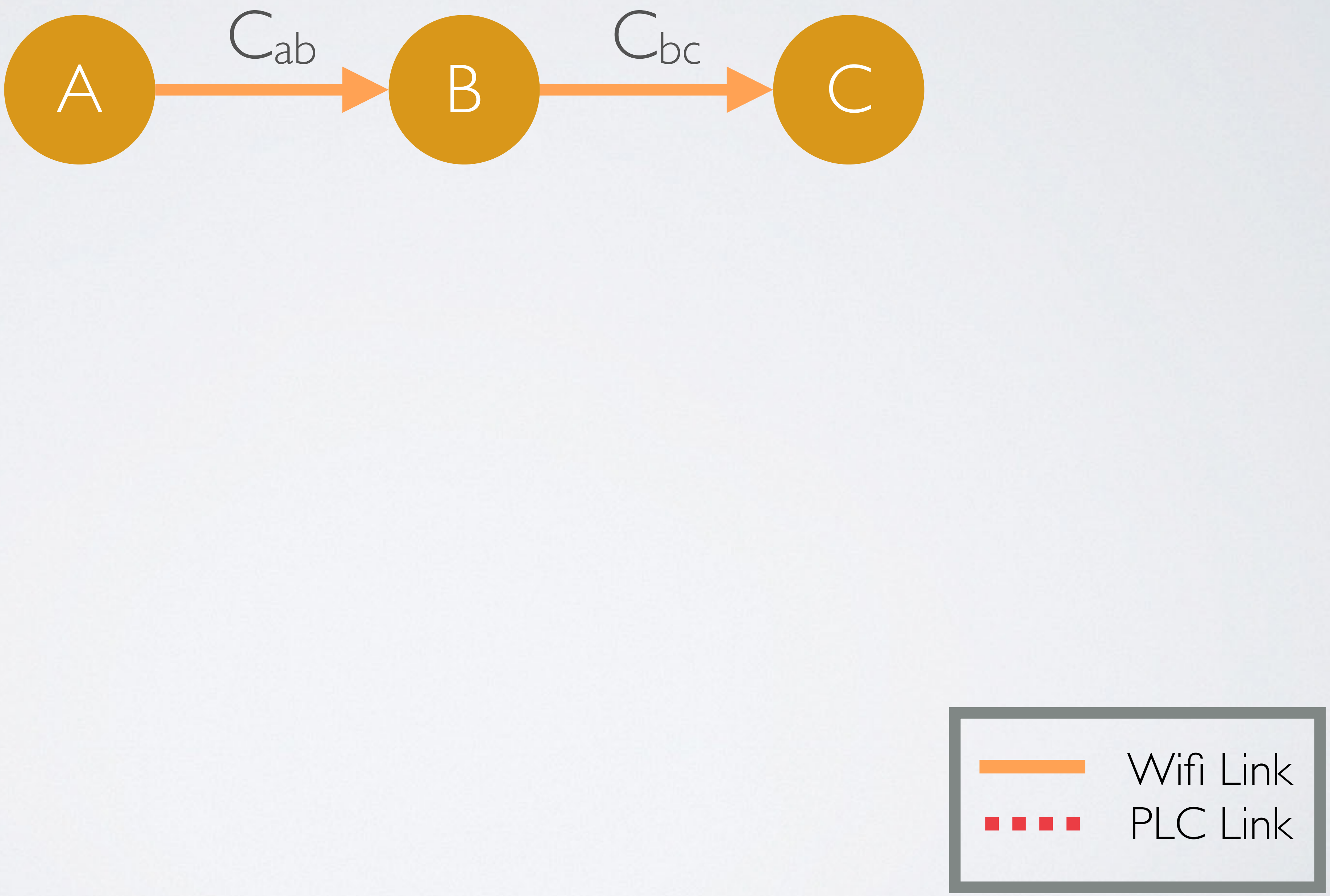

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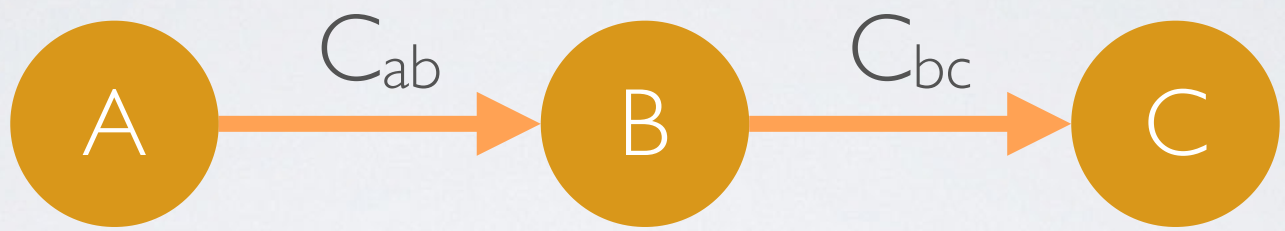
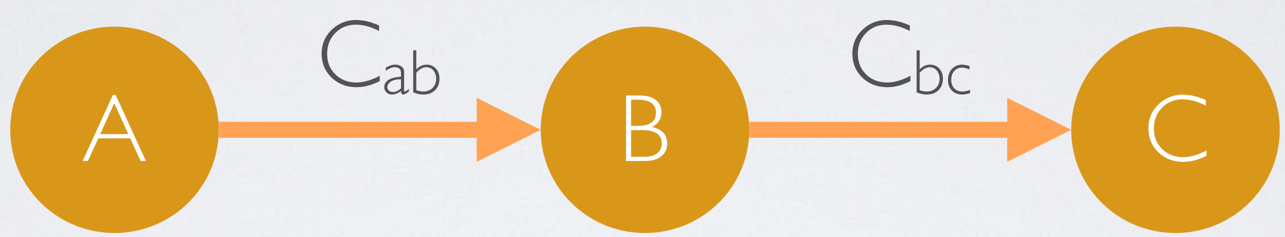


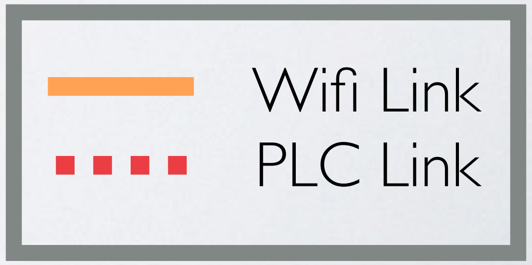
Not as straightforward!

EXISTING SOLUTION

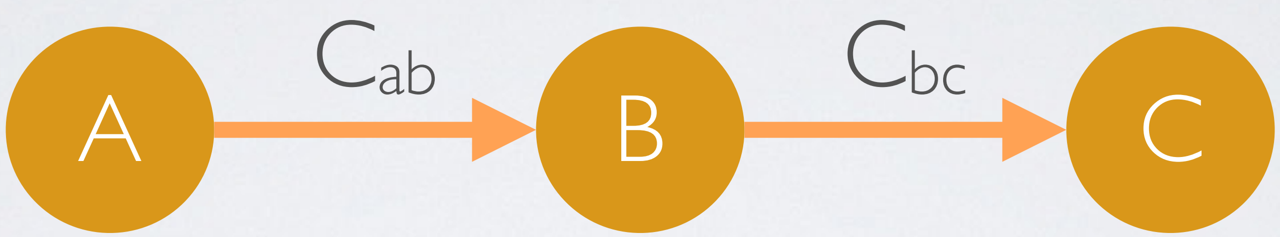


Not as straightforward!

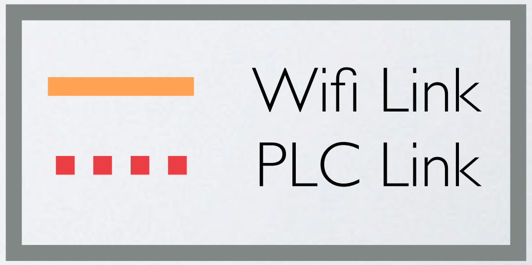
Reason : Interference



EXISTING SOLUTION



$$\frac{1}{\frac{1}{C_{ab}} + \frac{1}{C_{bc}}}$$



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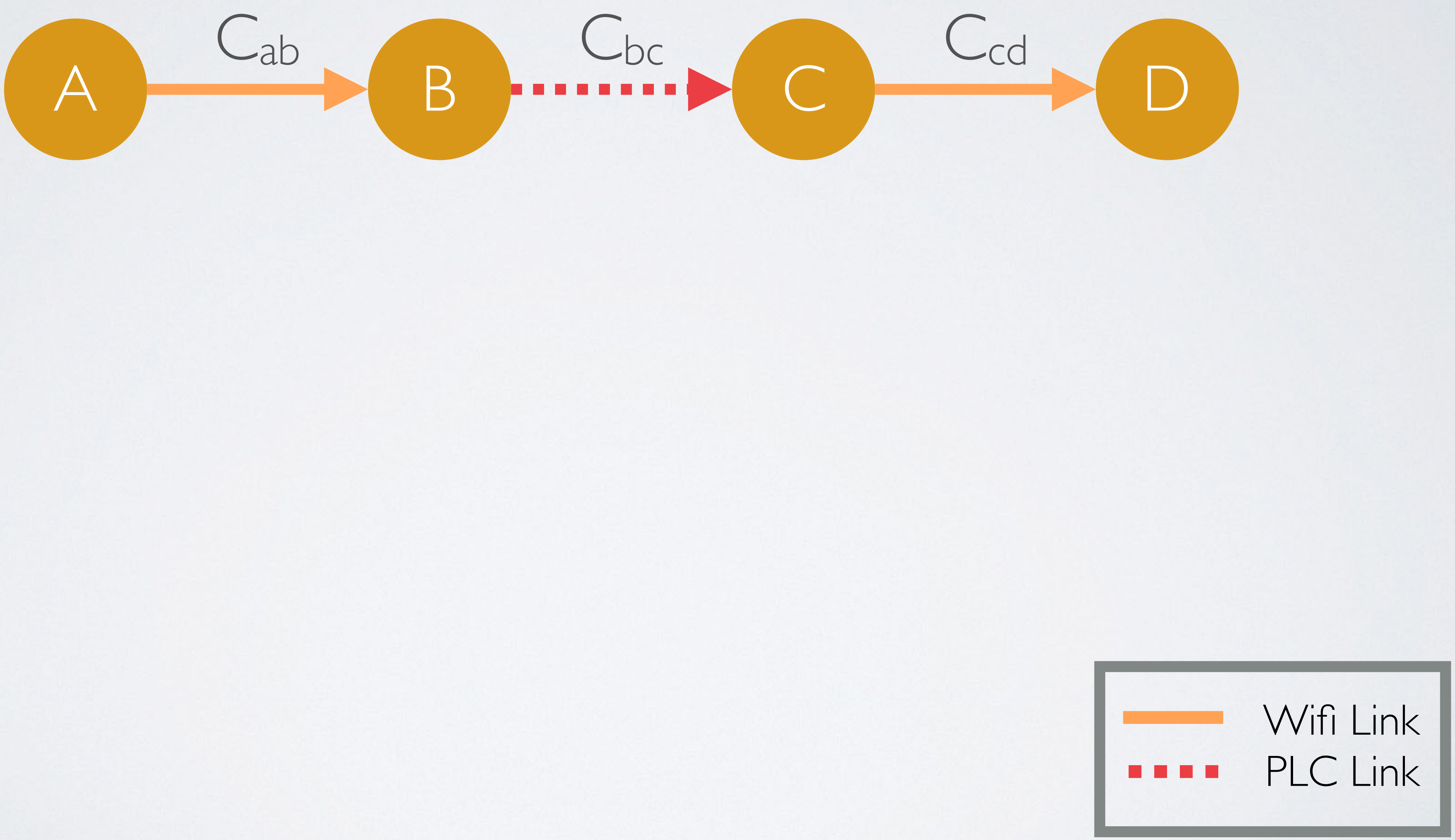

EXISTING SOLUTION

$$
\left.
\begin{array}{l}
min(\dfrac{1}{\dfrac{1}{C_{ab}}+\dfrac{1}{C_{cd}}}, C_{bc}) \\[3em]
min(C_{ab}, C_{bc}, C_{cd})
\end{array}
\right\}
\begin{array}{l}
\text{If interference} \\[3em]
\text{If no interference}
\end{array}
$$

EXISTING SOLUTION

$$\left.\begin{array}{l} min(\frac{1}{\frac{1}{C_{ab}}+\frac{1}{C_{cd}}}, C_{bc}) \\ \\ min(C_{ab}, C_{bc}, C_{cd}) \end{array}\right\} \begin{array}{l} \text{If interference} \\ \\ \text{If no interference} \end{array}$$

Assumes interference is binary!

Assumes C can always tell when A is transmitting (And vice-versa) !

EXISTING SOLUTION

$$\begin{cases} min(\dfrac{1}{\dfrac{1}{C_{ab}} + \dfrac{1}{C_{cd}}}, C_{bc}) & \text{If interference} \\ min(C_{ab}, C_{bc}, C_{cd}) & \text{If no interference} \end{cases}$$

Assumes interference is binary!

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IDEA 1 : USE LINK CAPACITIES

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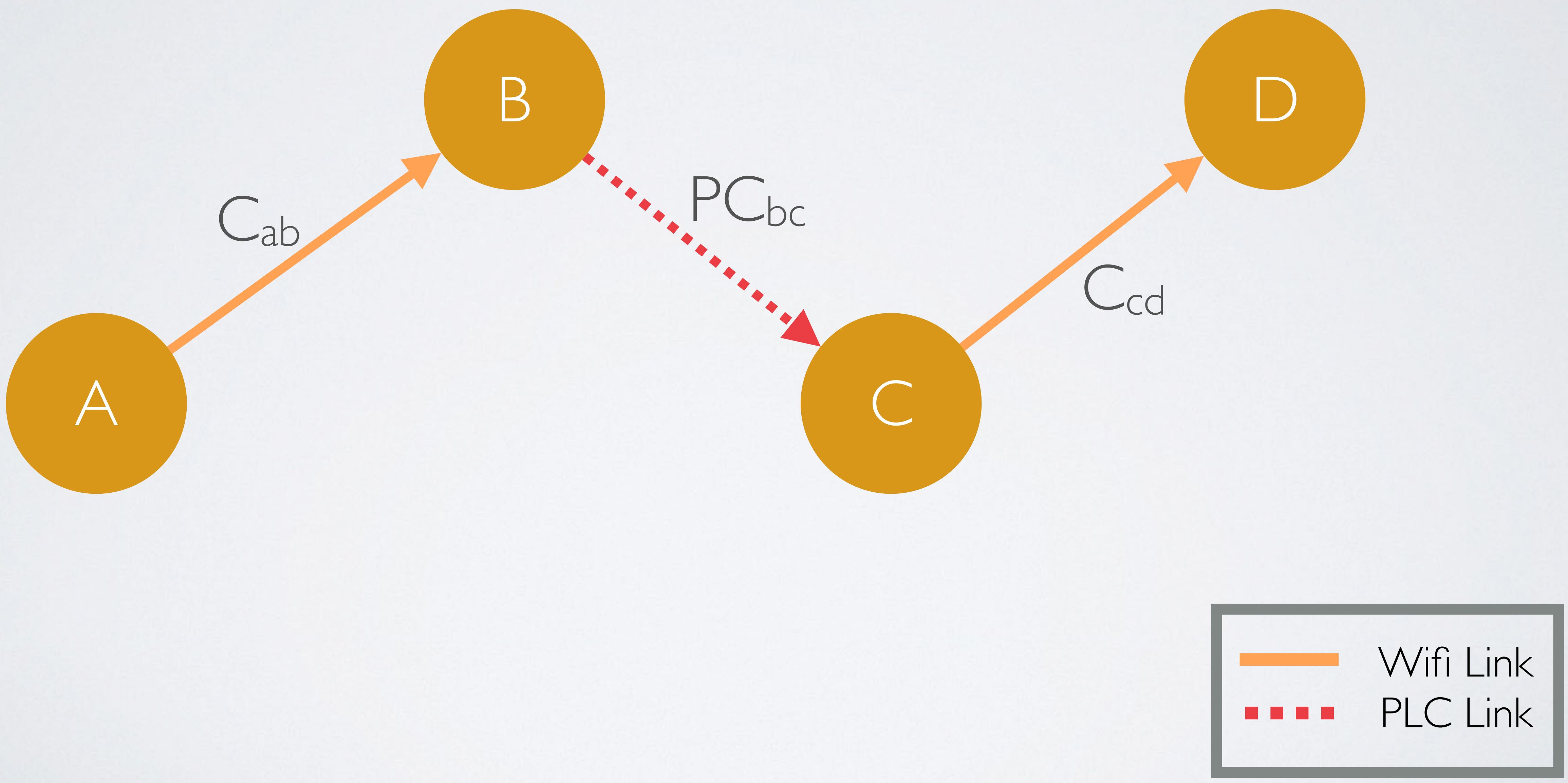

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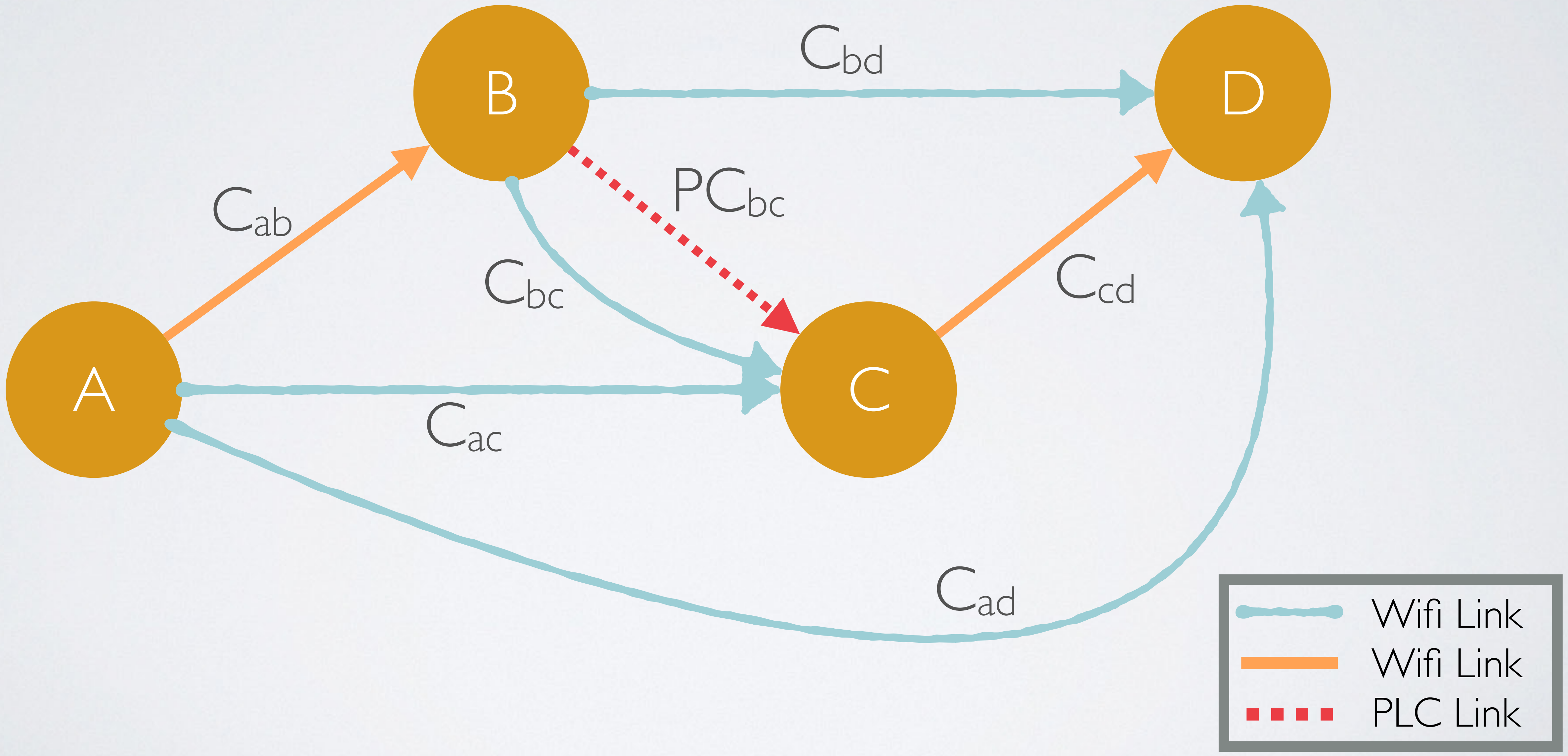

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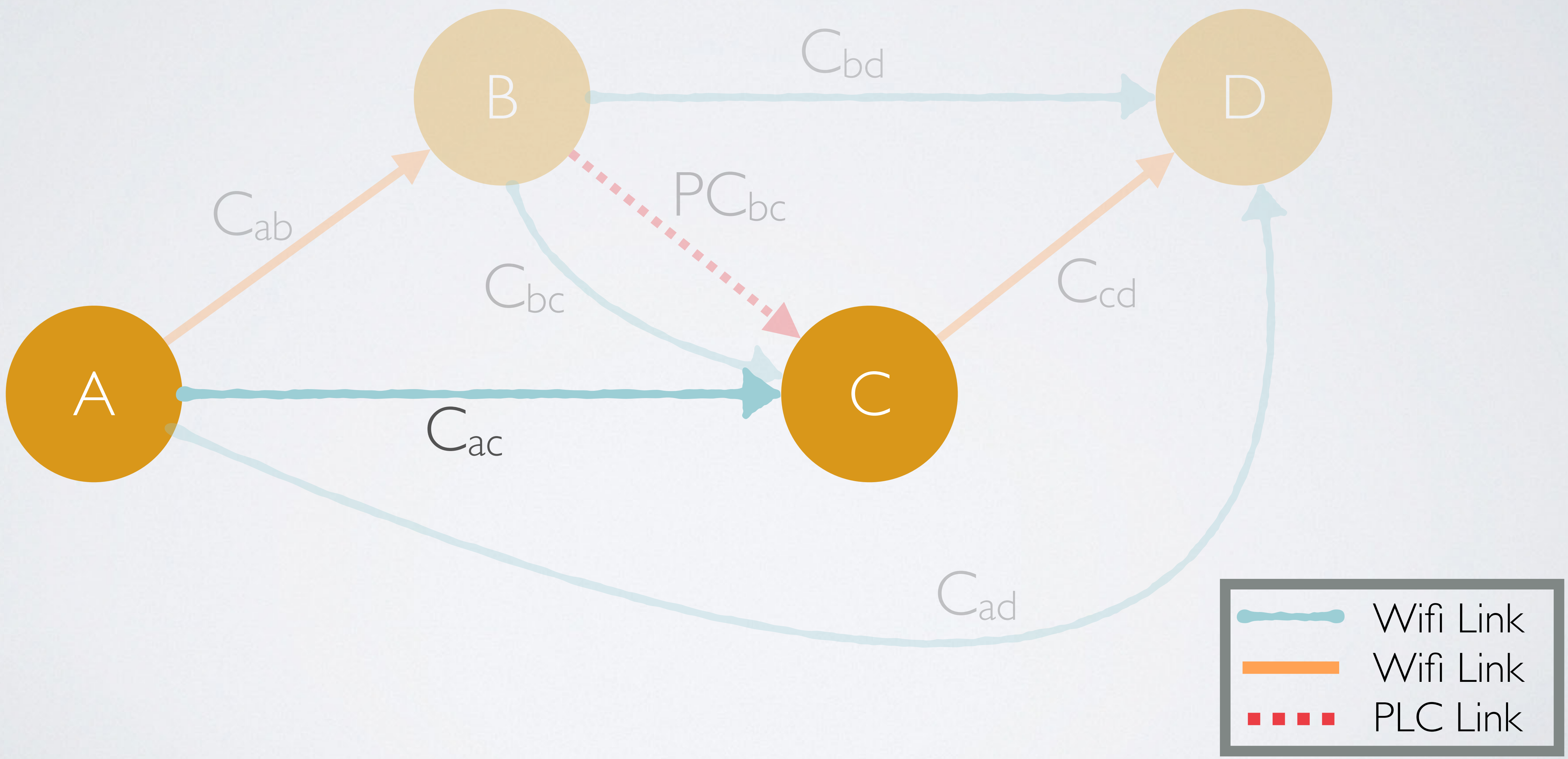

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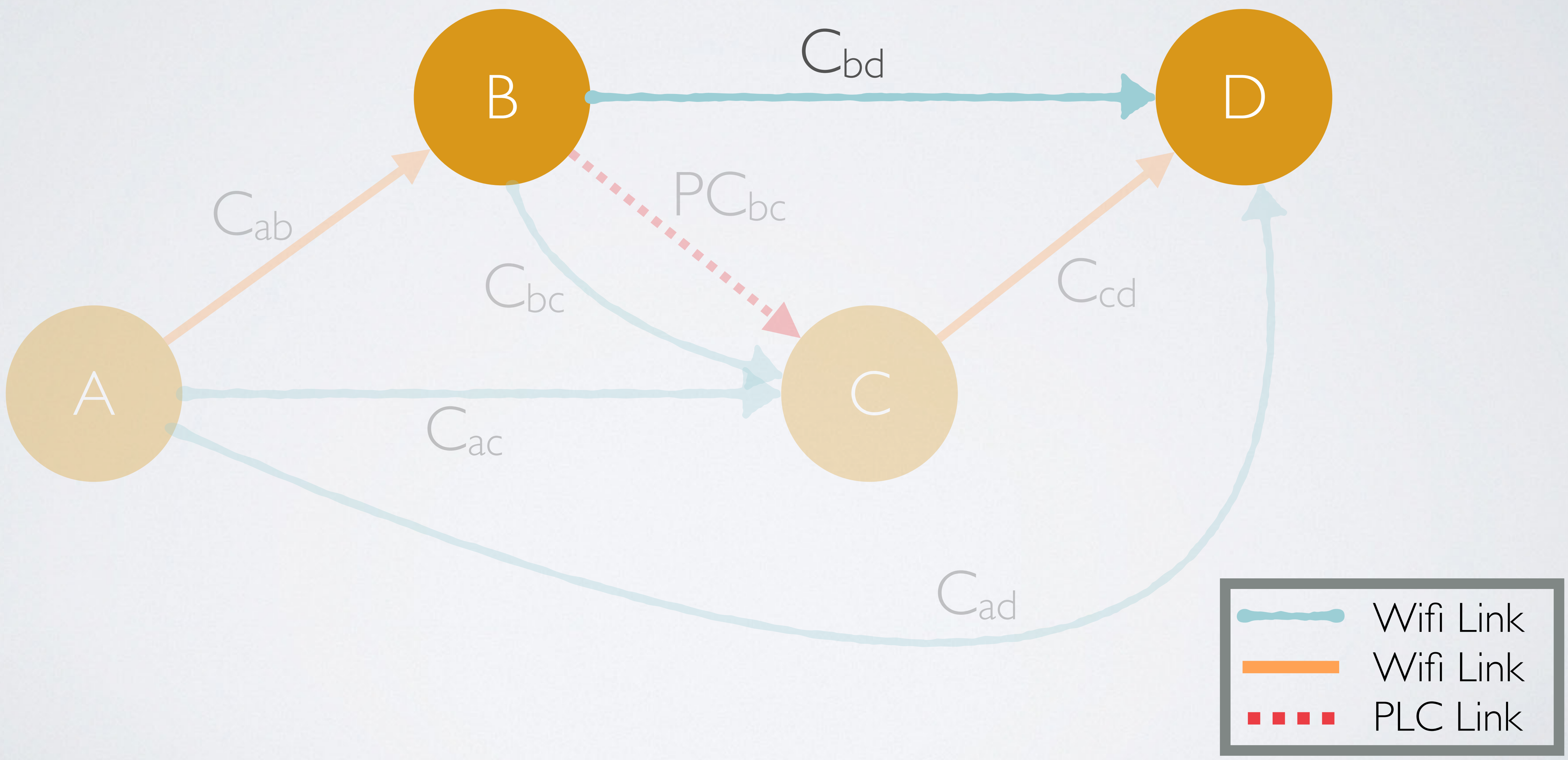

MODEL AND DATA

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$$Y = W_1^T . X_{LC}$$

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$$Y = W_1^T . X_{LC} + W_2^T . X_{BP}$$

MODEL AND DATA

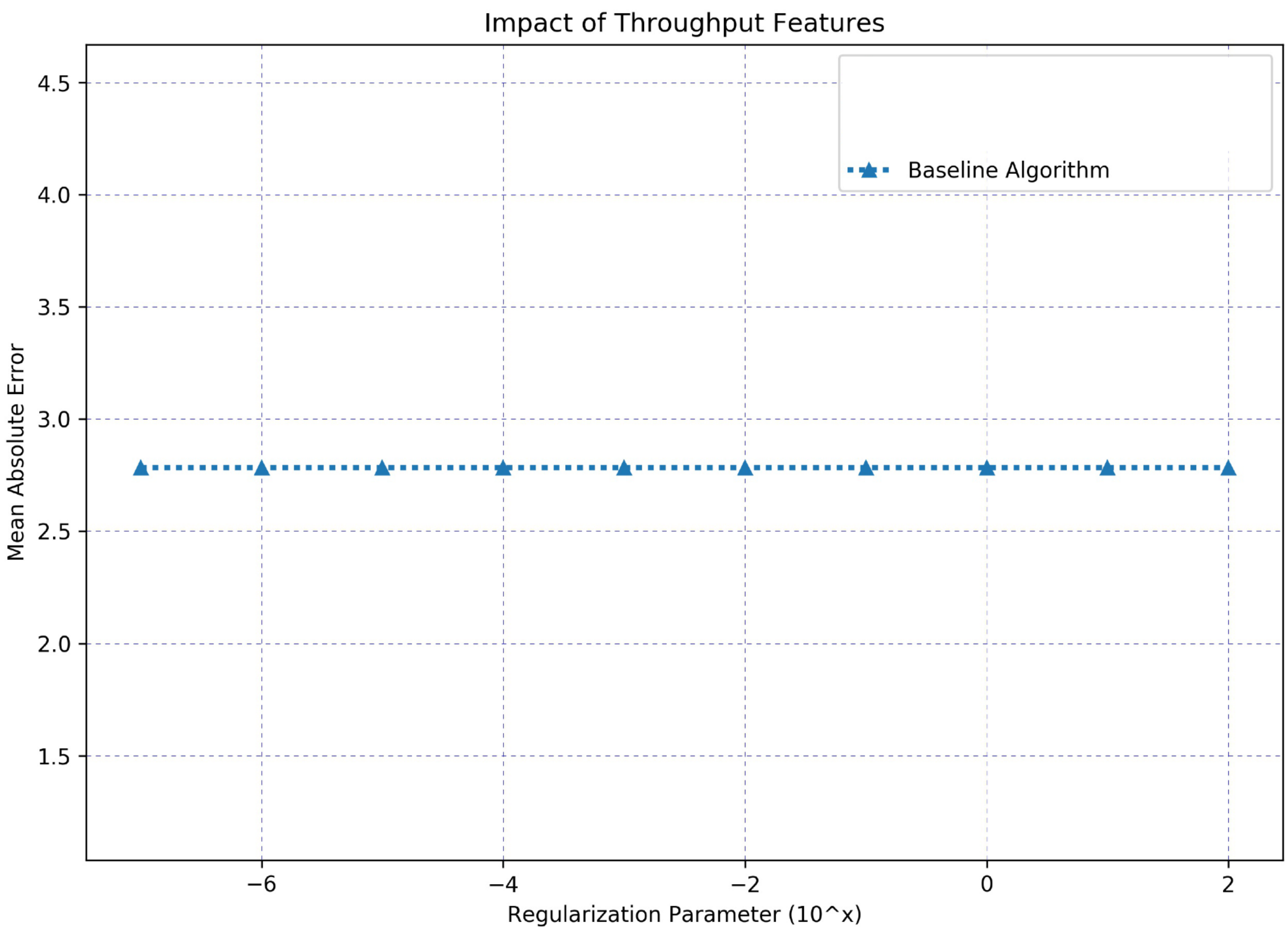
$$Y = W_1^T.X_{LC} + W_2^T.X_{BP} + W_3^T.P^2(X_{LC} \times X_{BP})$$

MODEL AND DATA

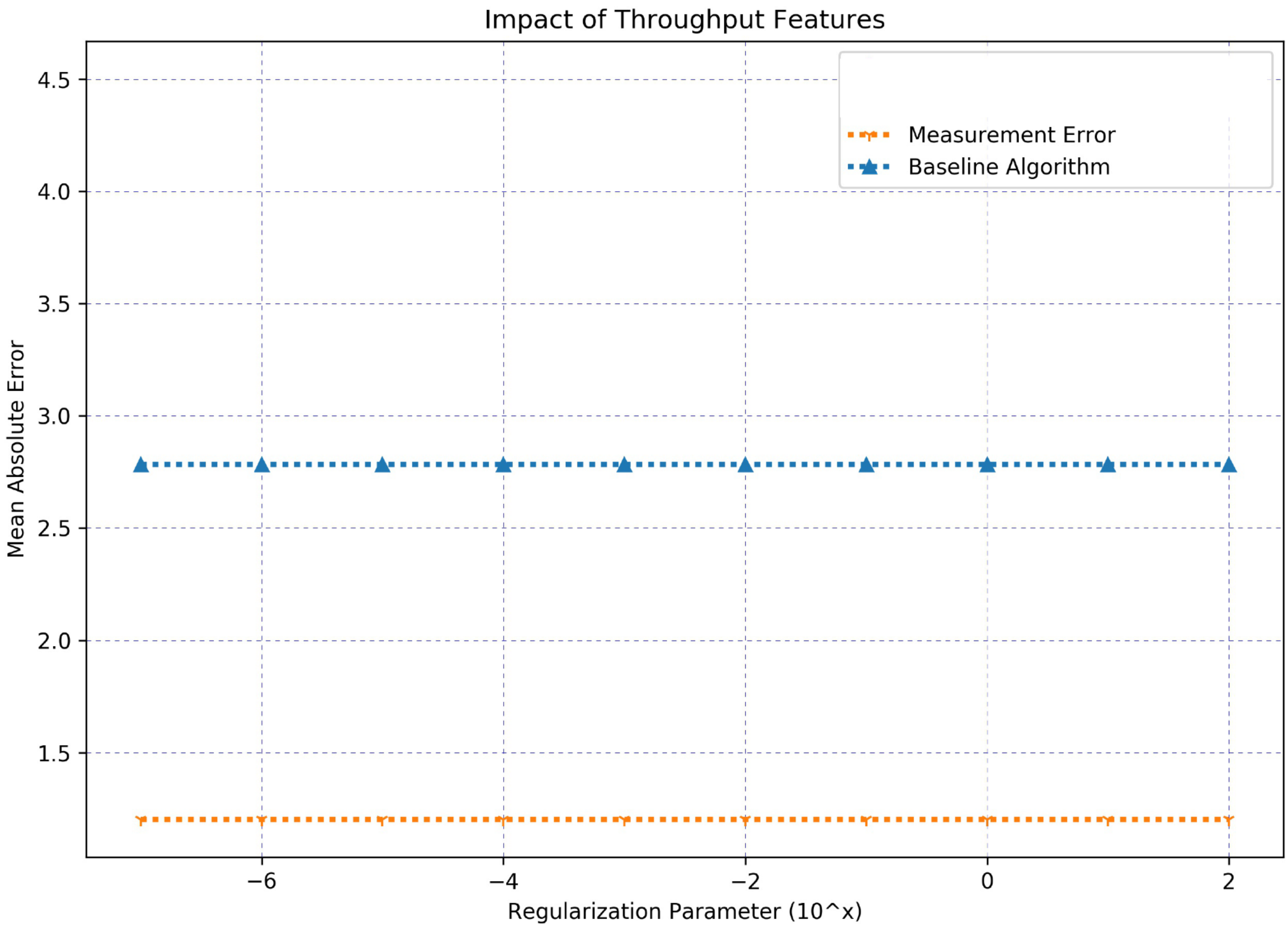
$$Y = W_1^T.X_{LC} + W_2^T.X_{BP} + W_3^T.P^2(X_{LC} \times X_{BP})$$

Collected on a 22 node testbed using UDP traffic.

WPW Paths


Impact of Throughput Features
Mean Absolute Error
4.5
4.0
3.5
3.0
2.5
2.0
1.5
−6
−4
−2
0
2
Regularization Parameter (10^x)
Baseline Algorithm

WPW Paths



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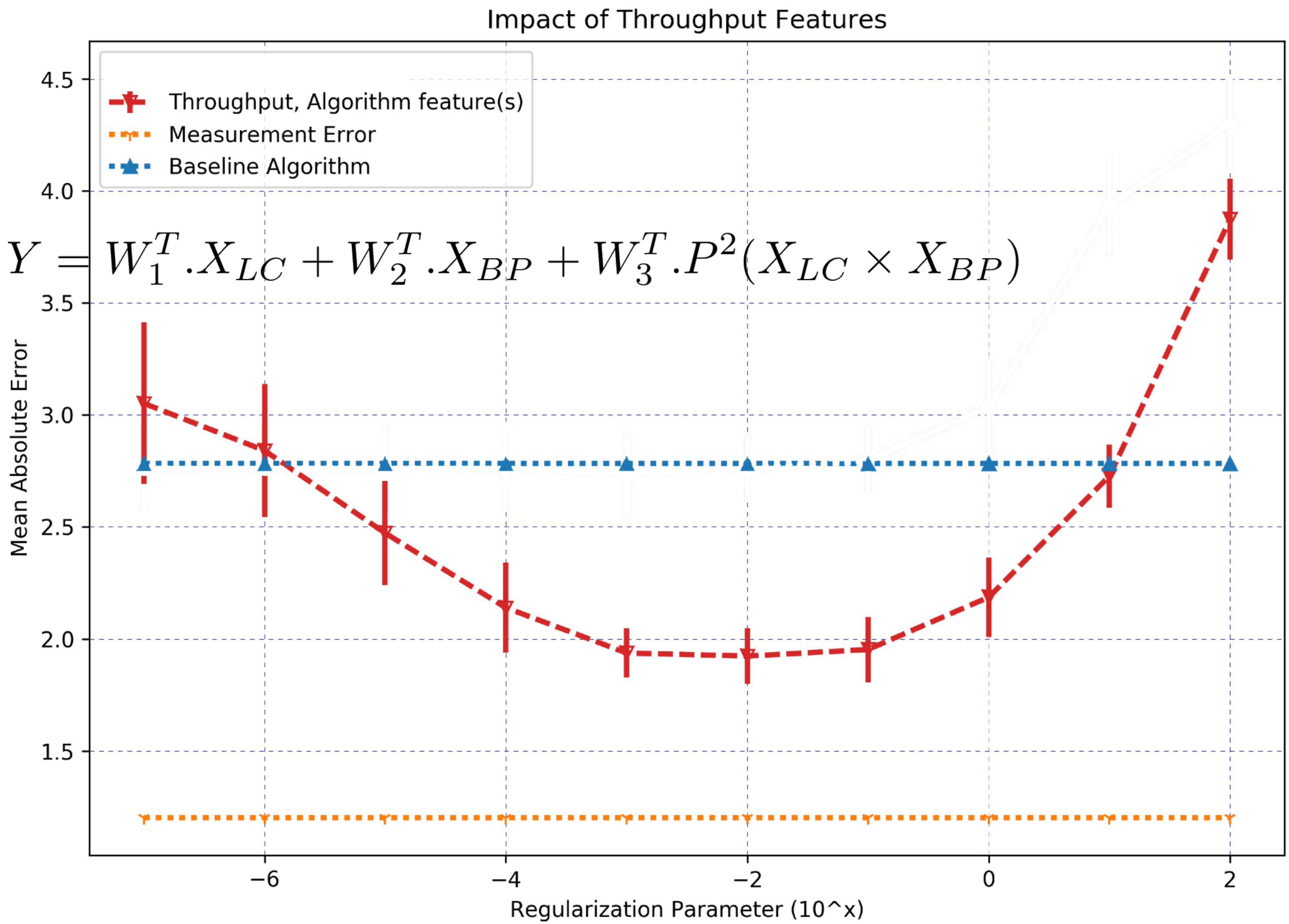
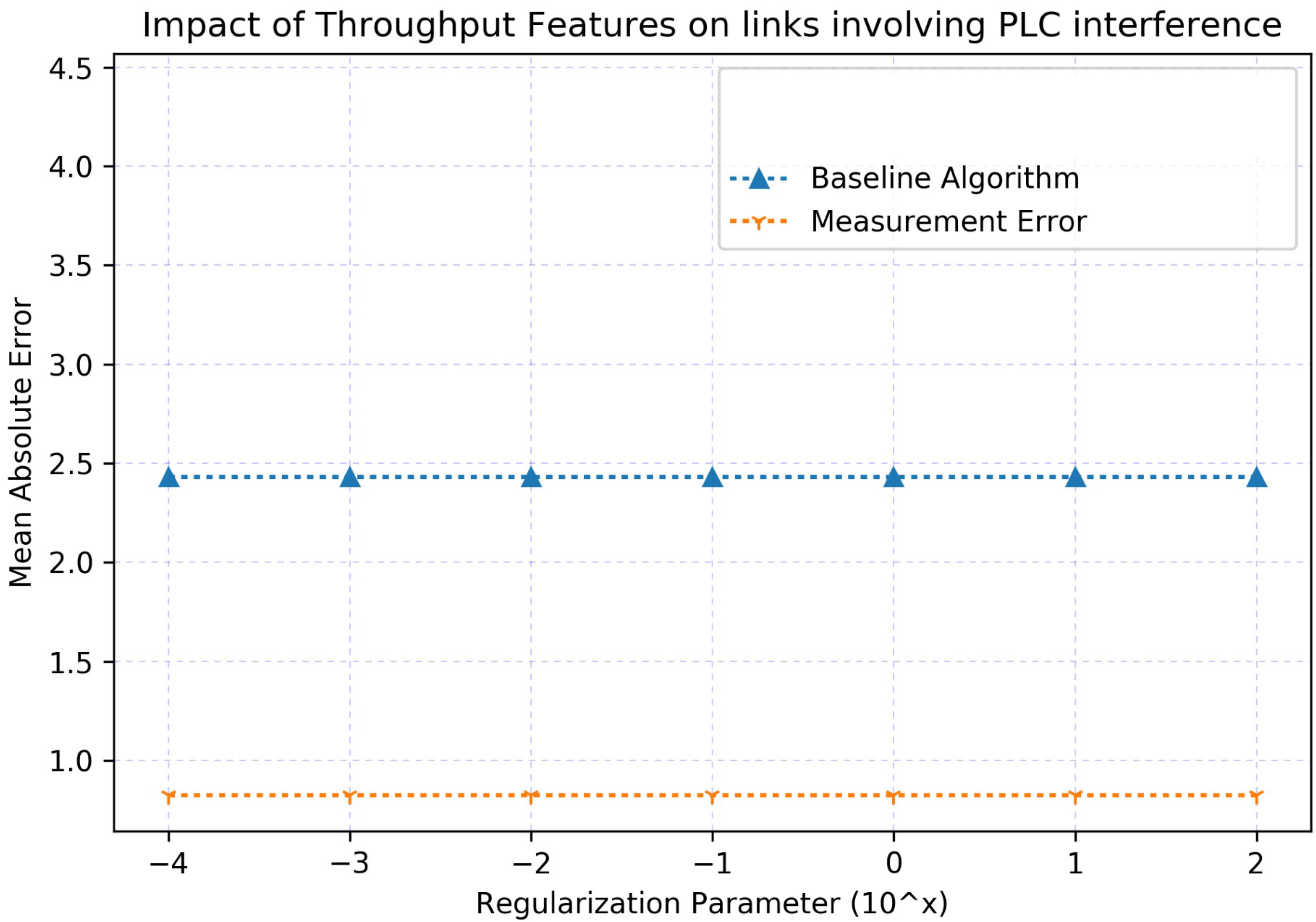


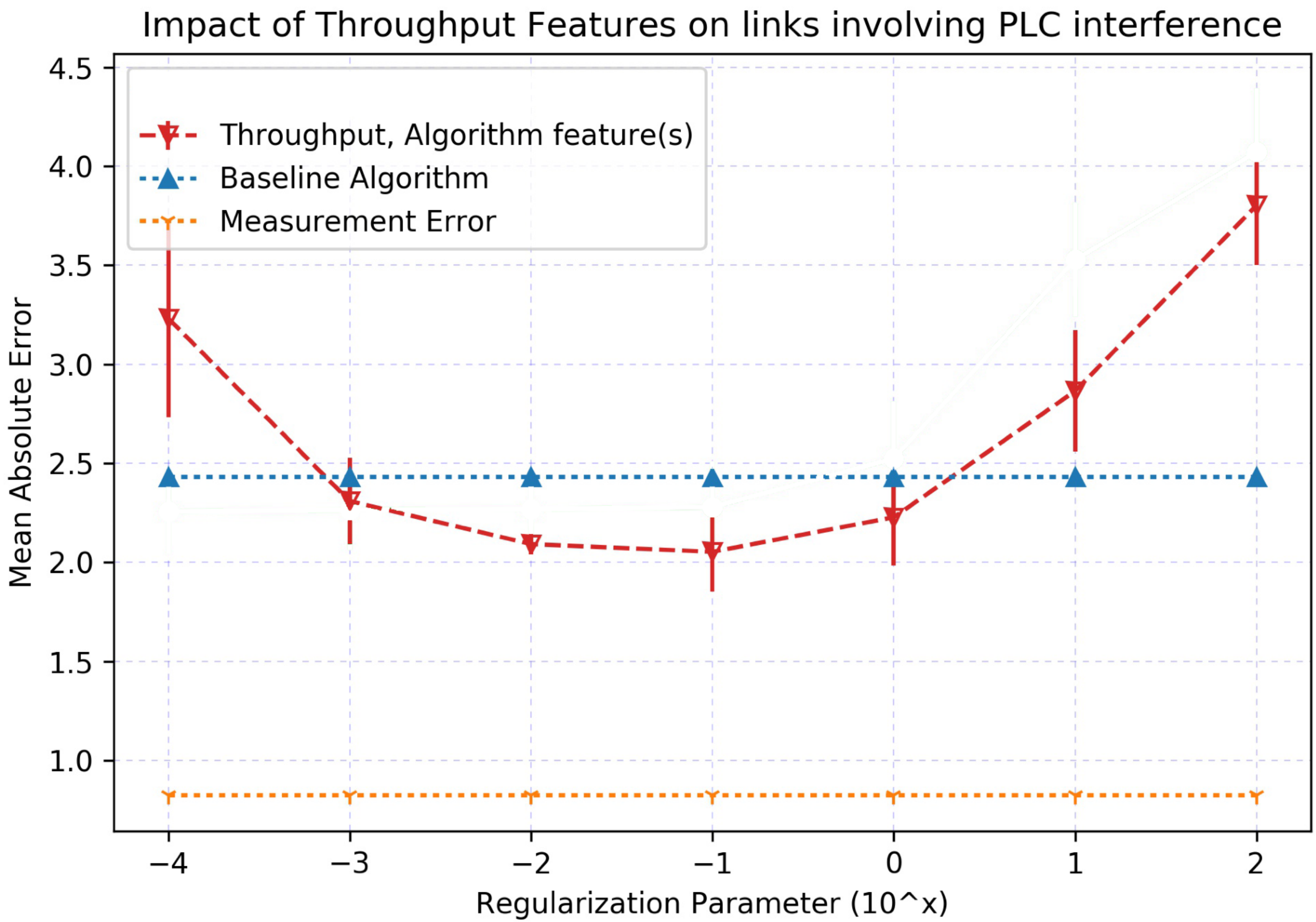
$$Y = W_1^T.X_{LC} + W_2^T.X_{BP} + W_3^T.P^2(X_{LC} \times X_{BP})$$

PWP Paths



Impact of Throughput Features on links involving PLC interference
Mean Absolute Error
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Baseline Algorithm
Measurement Error
−4
−3
−2
−1
0
1
2
Regularization Parameter (10^x)

PWP Paths



Impact of Throughput Features on links involving PLC interference
Throughput, Algorithm feature(s)
Baseline Algorithm
Measurement Error
Mean Absolute Error
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
−4
−3
−2
−1
0
1
2
Regularization Parameter (10^x)

IDEA 2 : LINK INTERFERENCE RATIO

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- Metric to measure interference

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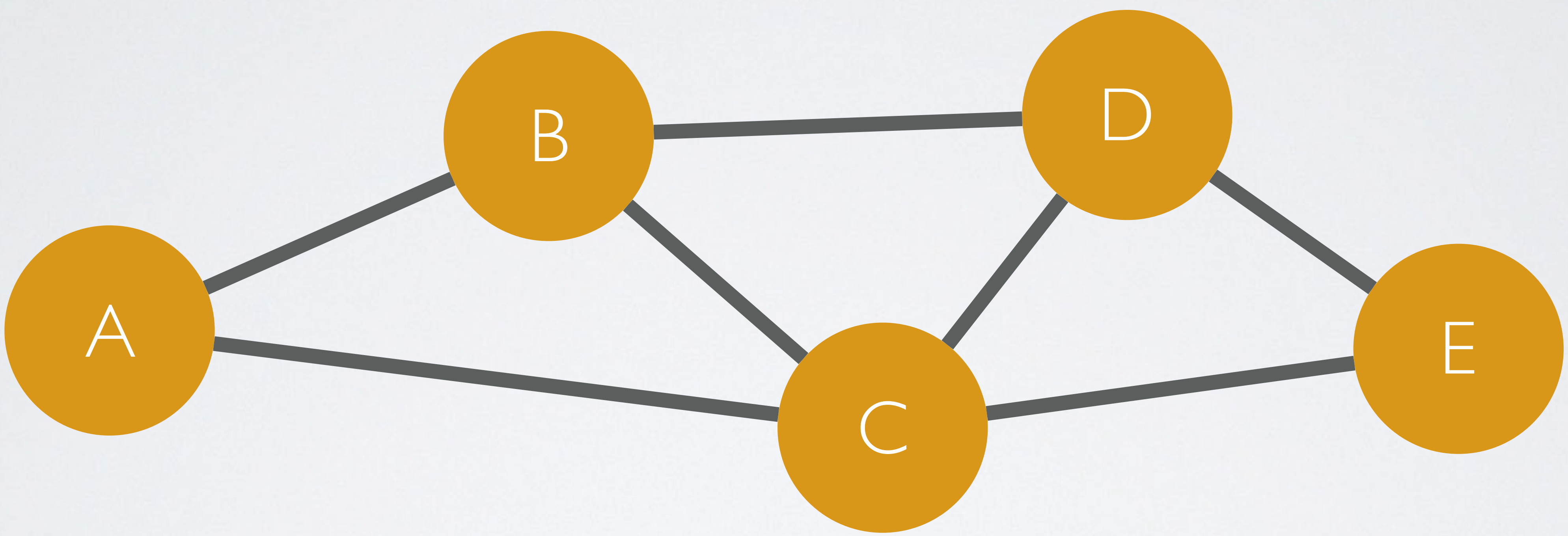

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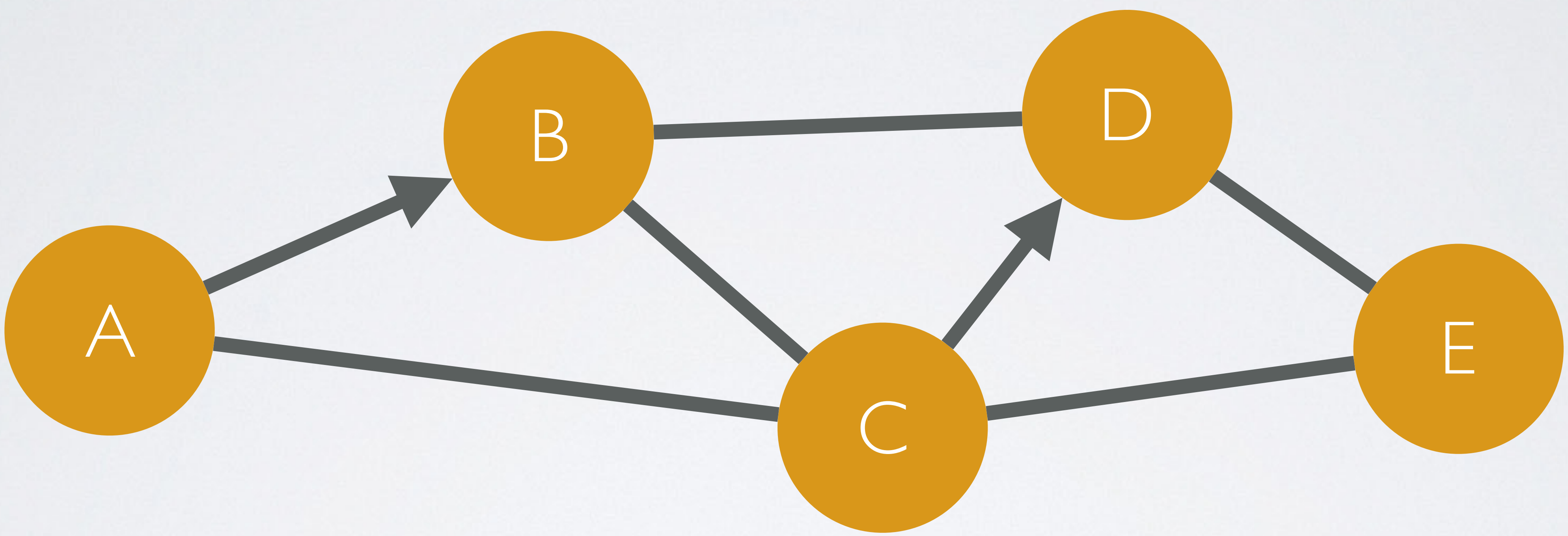
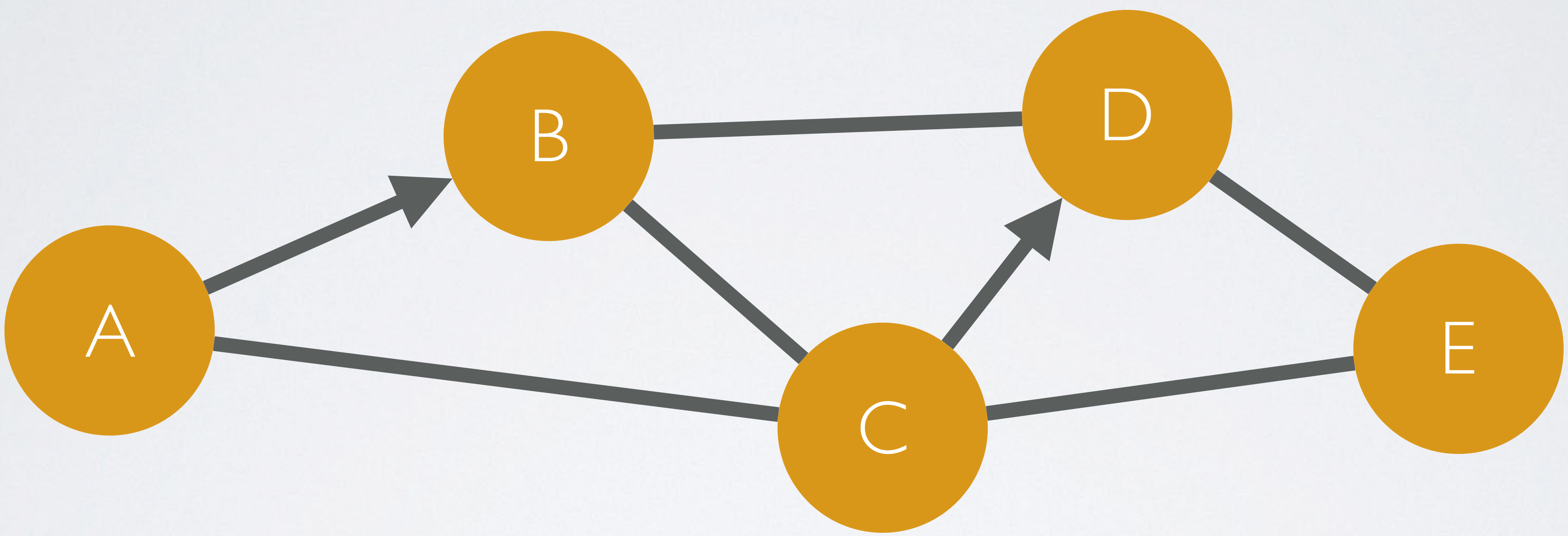


Measure LIR of link AB and CD

IDEA 2 : LINK INTERFERENCE RATIO

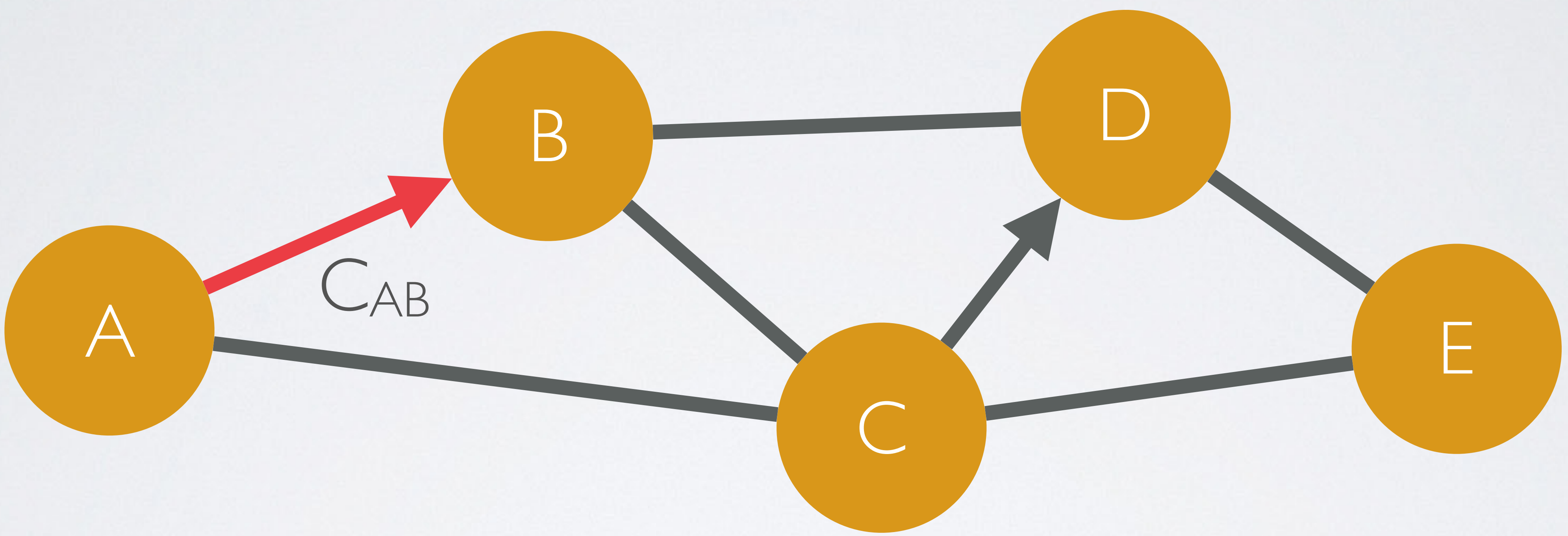
- Metric to measure interference



Step 1: Measure Individual Link Capacities separately

IDEA 2 : LINK INTERFERENCE RATIO

- Metric to measure interference



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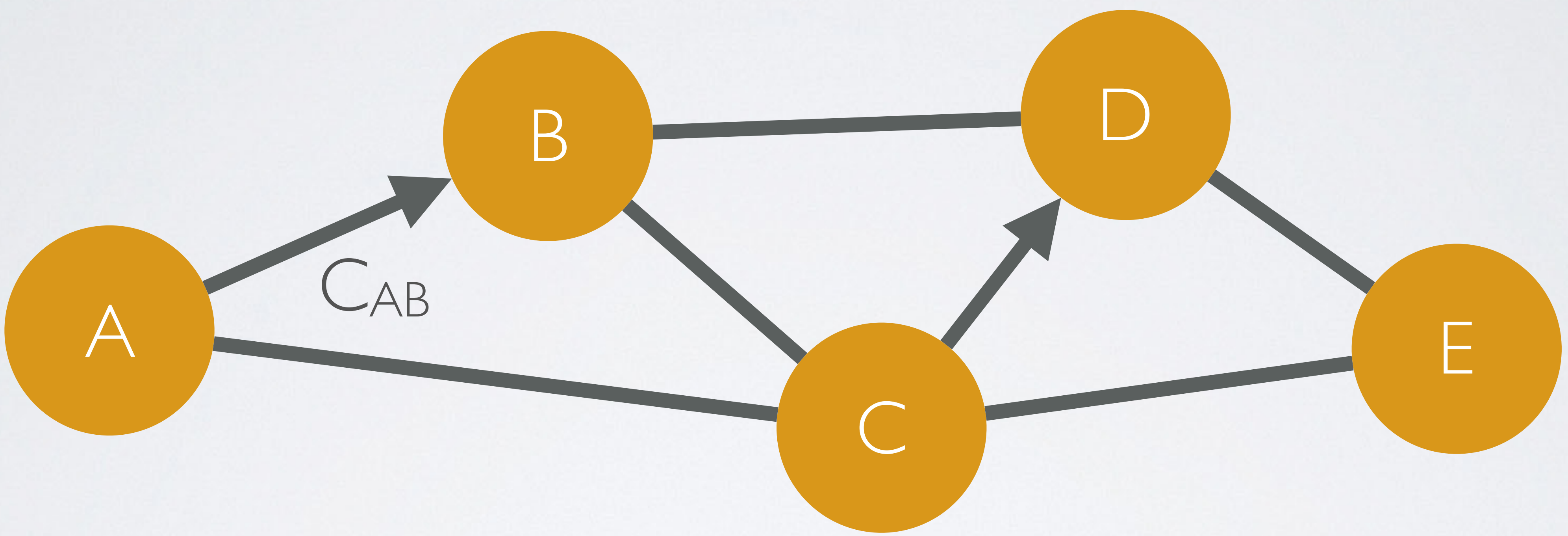

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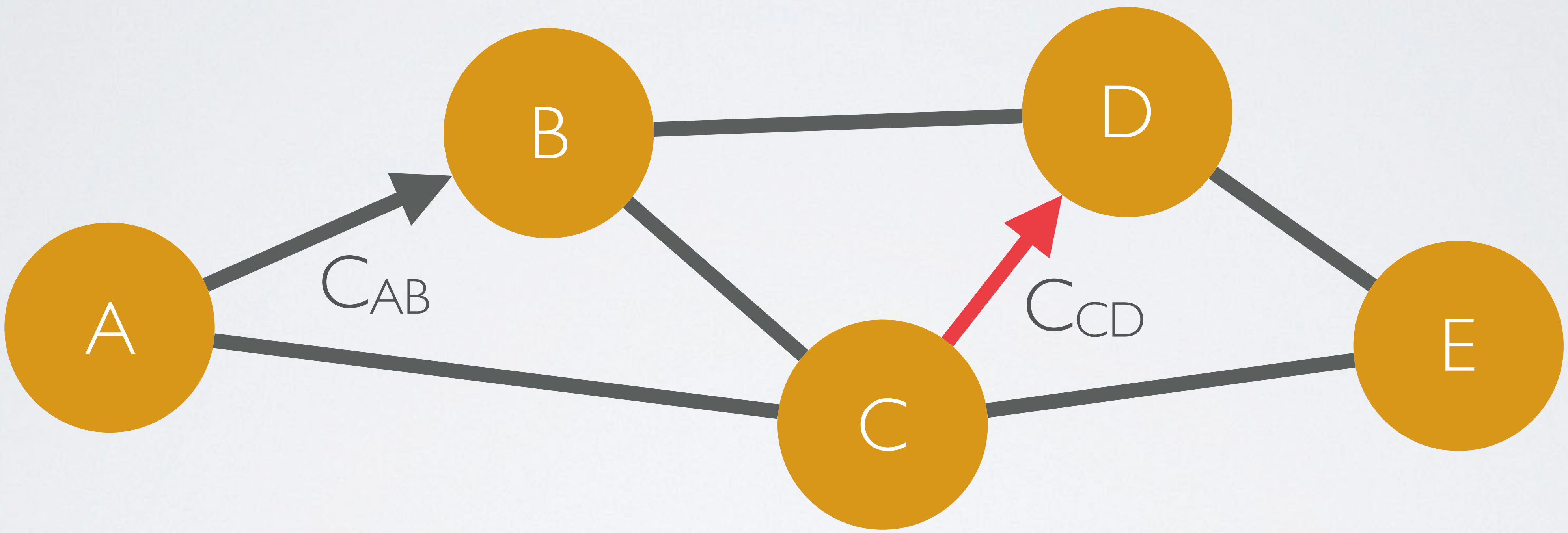

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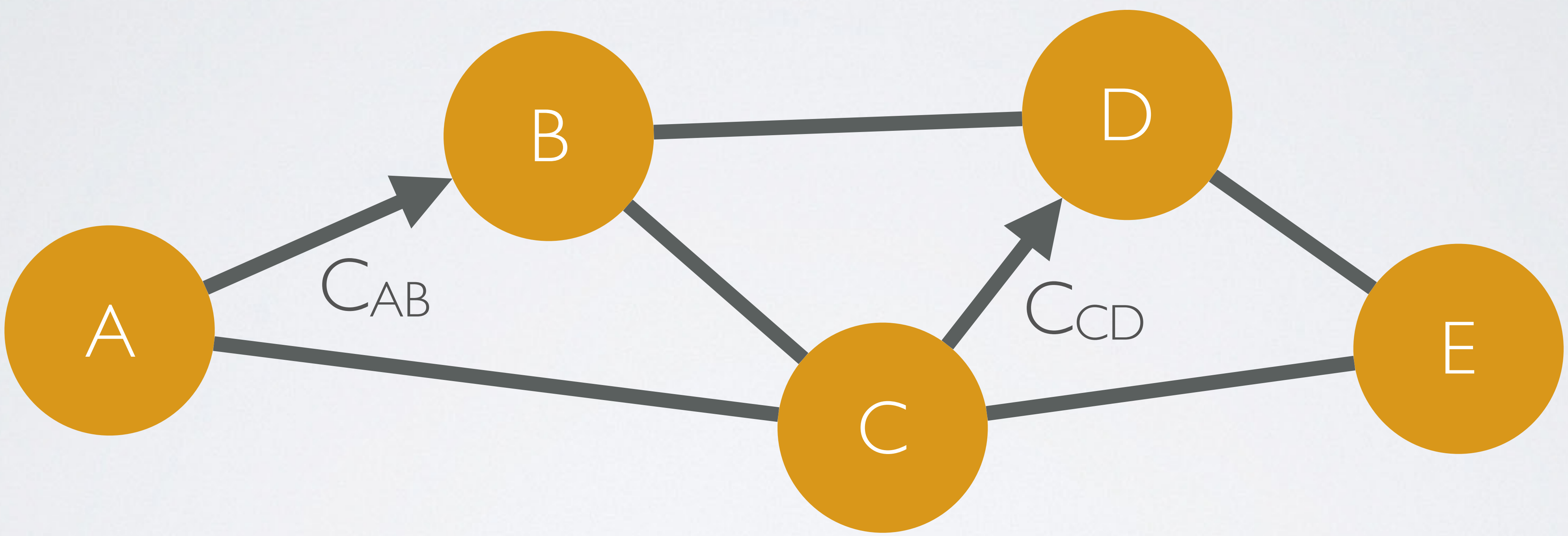
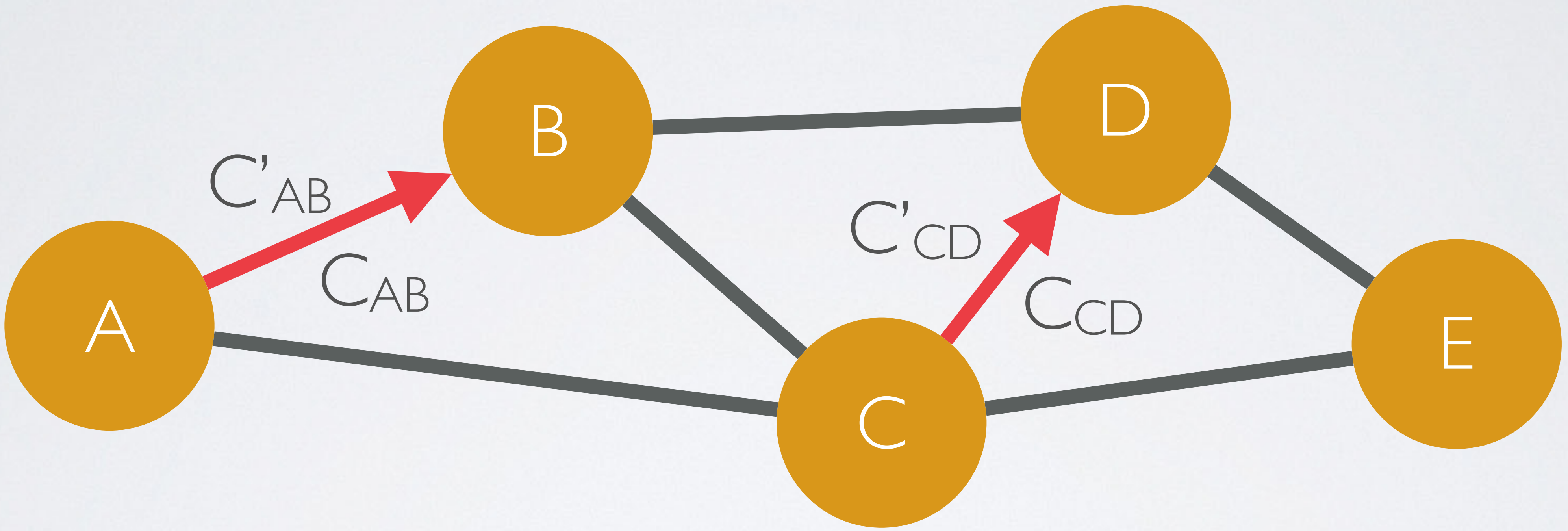
- Metric to measure interference



Step 2: Measure Individual Link Capacities Simultaneously

IDEA 2 : LINK INTERFERENCE RATIO

- Metric to measure interference



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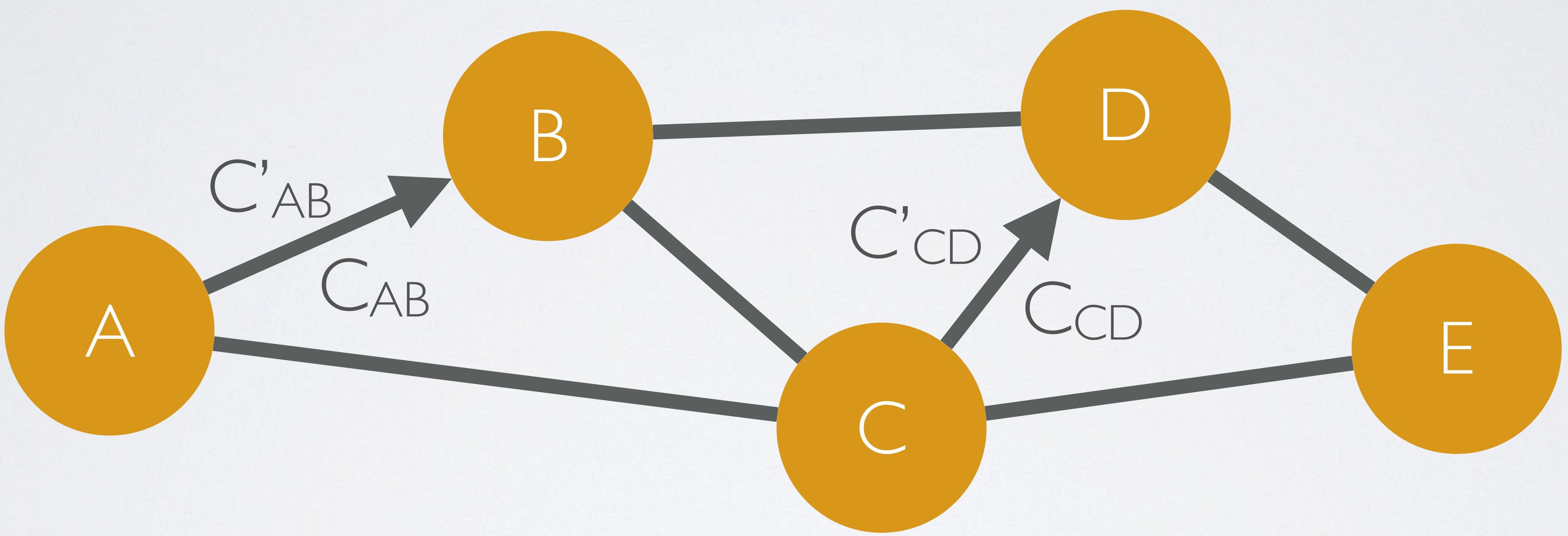
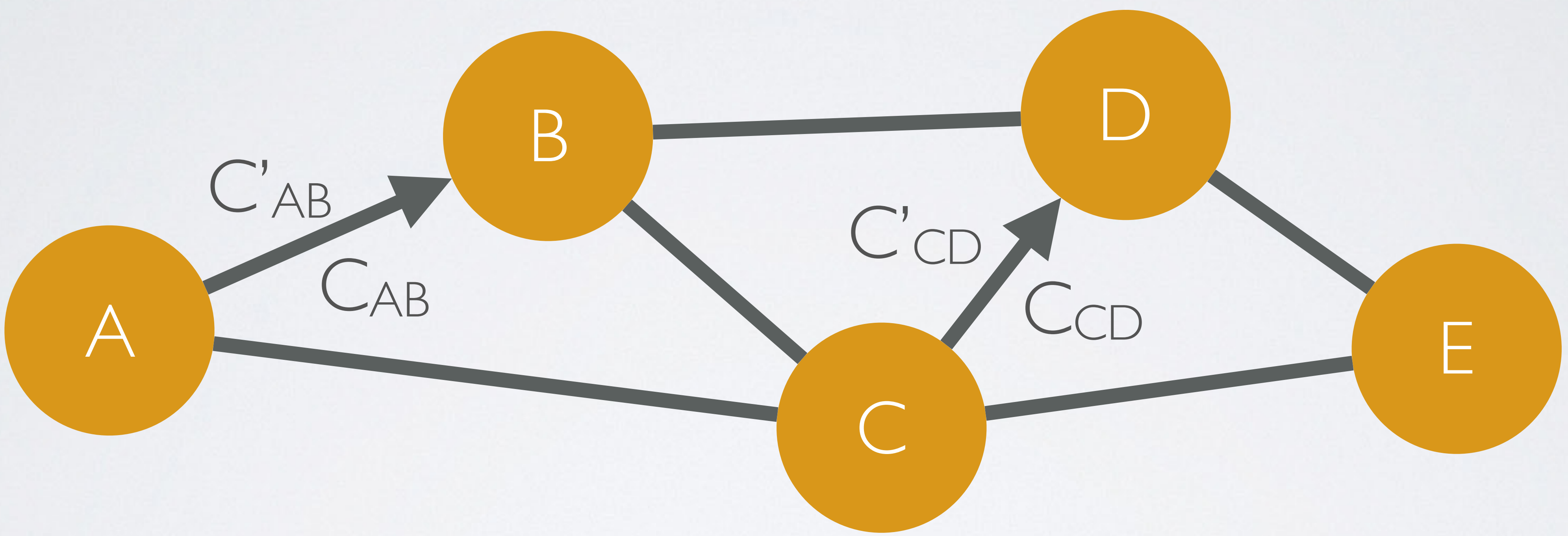


Step 3: Compute LIR

IDEA 2 : LINK INTERFERENCE RATIO

- Metric to measure interference



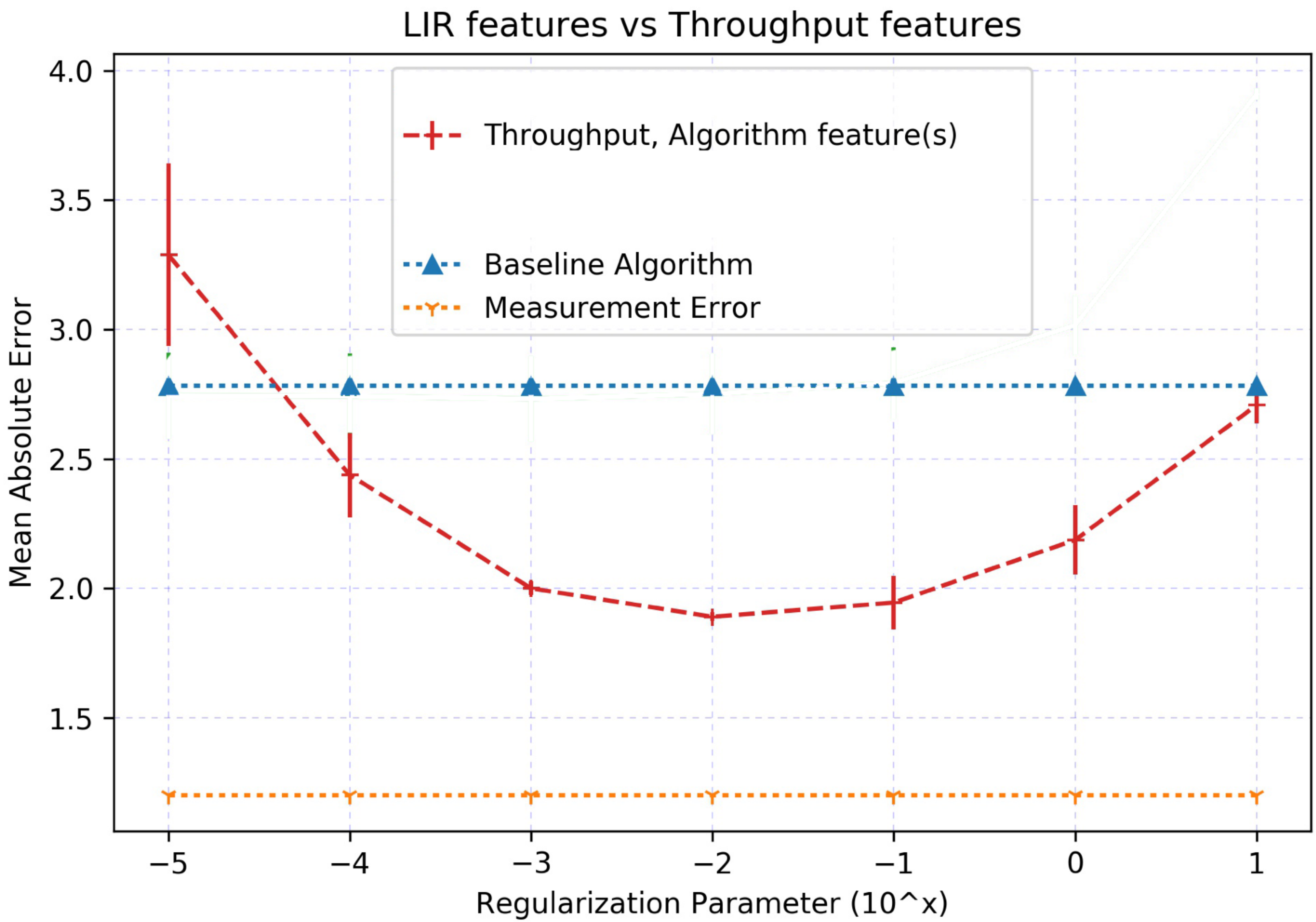
Step 3: Compute LIR

$$\frac{C'_{AB} + C'_{CD}}{C_{AB} + C_{CD}}$$

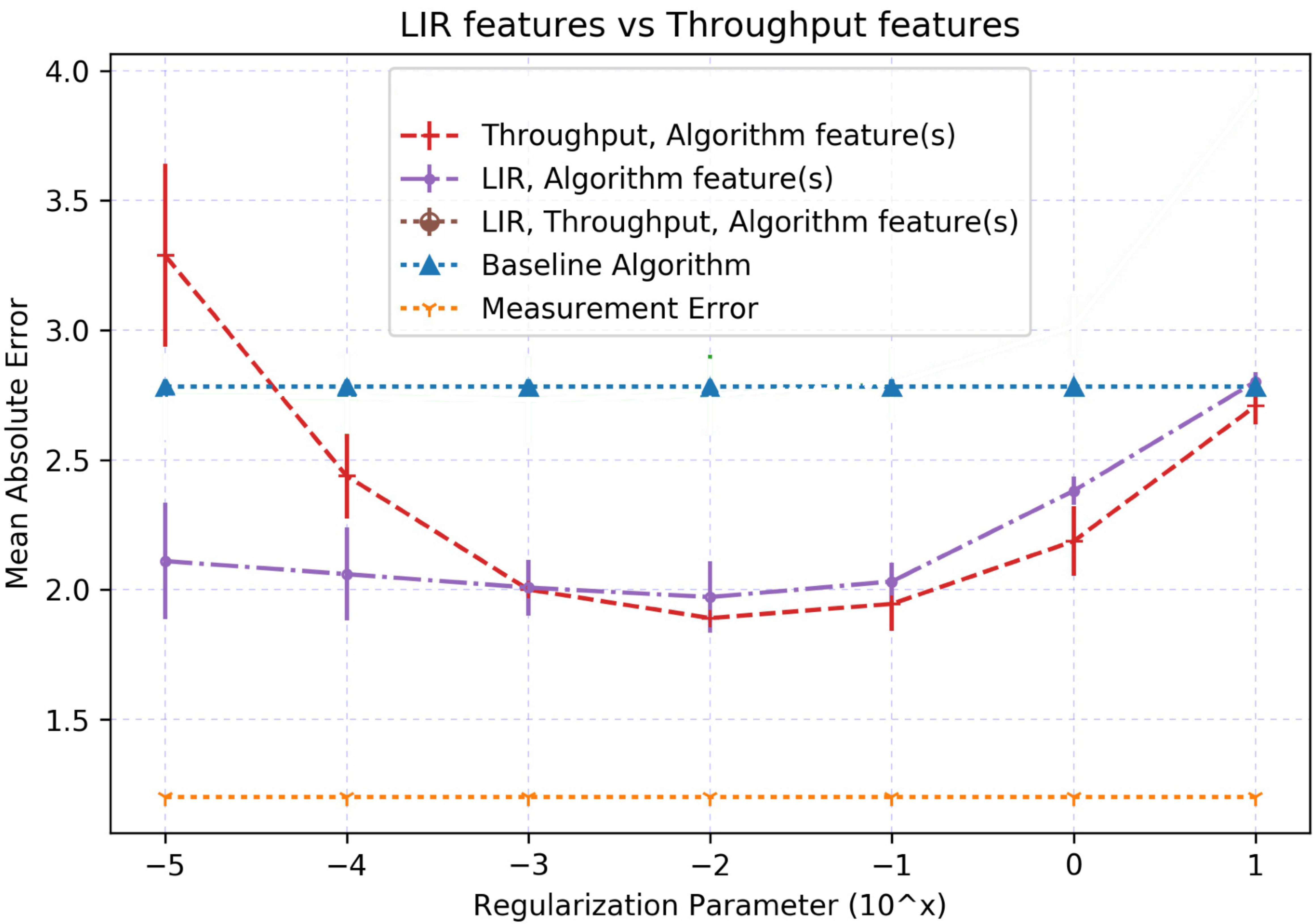
LIR VS THROUGHPUT

- Requires $\mathbf{n^2}$ measurements for an n node network.
- Throughput features require **n** measurements.

WPW Paths


LIR features vs Throughput features
Throughput, Algorithm feature(s)
Baseline Algorithm
Measurement Error
Mean Absolute Error
4.0
3.5
3.0
2.5
2.0
1.5
−5
−4
−3
−2
−1
0
1
Regularization Parameter (10^x)

WPW Paths



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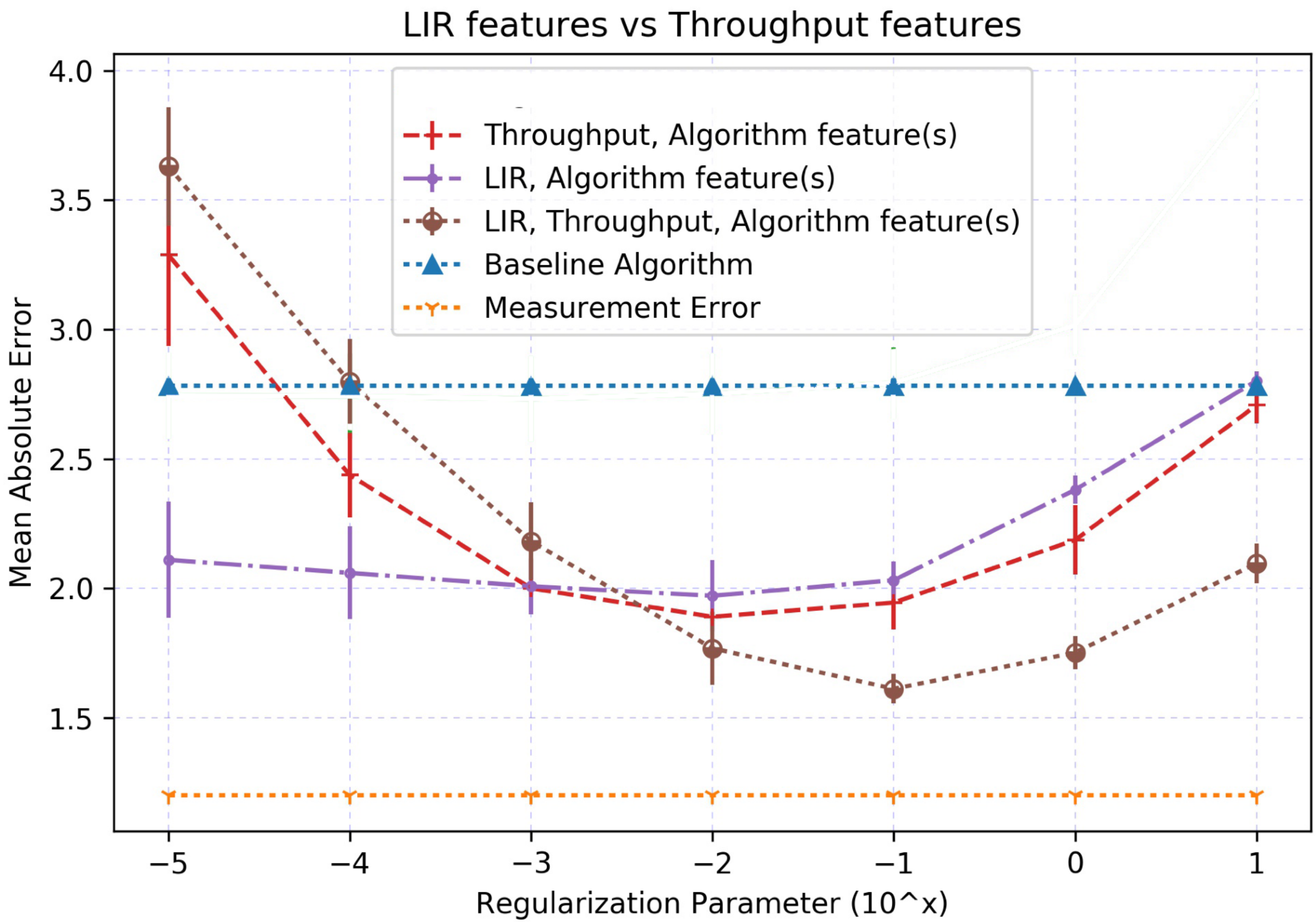
WPW Paths



LIR features vs Throughput features
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LIR, Algorithm feature(s)
LIR, Throughput, Algorithm feature(s)
Baseline Algorithm
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−5
−4
−3
−2
−1
0
1
Regularization Parameter (10^x)

IDEA 3 : NETWORK WIDE FEATURES

[1] Grover, A., & Leskovec, J. (2016, August). node2vec: Scalable feature learning for networks. In *Proceedings of the 22nd ACM SIGKDD international conference on Knowledge discovery and data mining* (pp. 855-864). ACM.

IDEA 3 : NETWORK WIDE FEATURES

- Node2Vec Embeddings[1]

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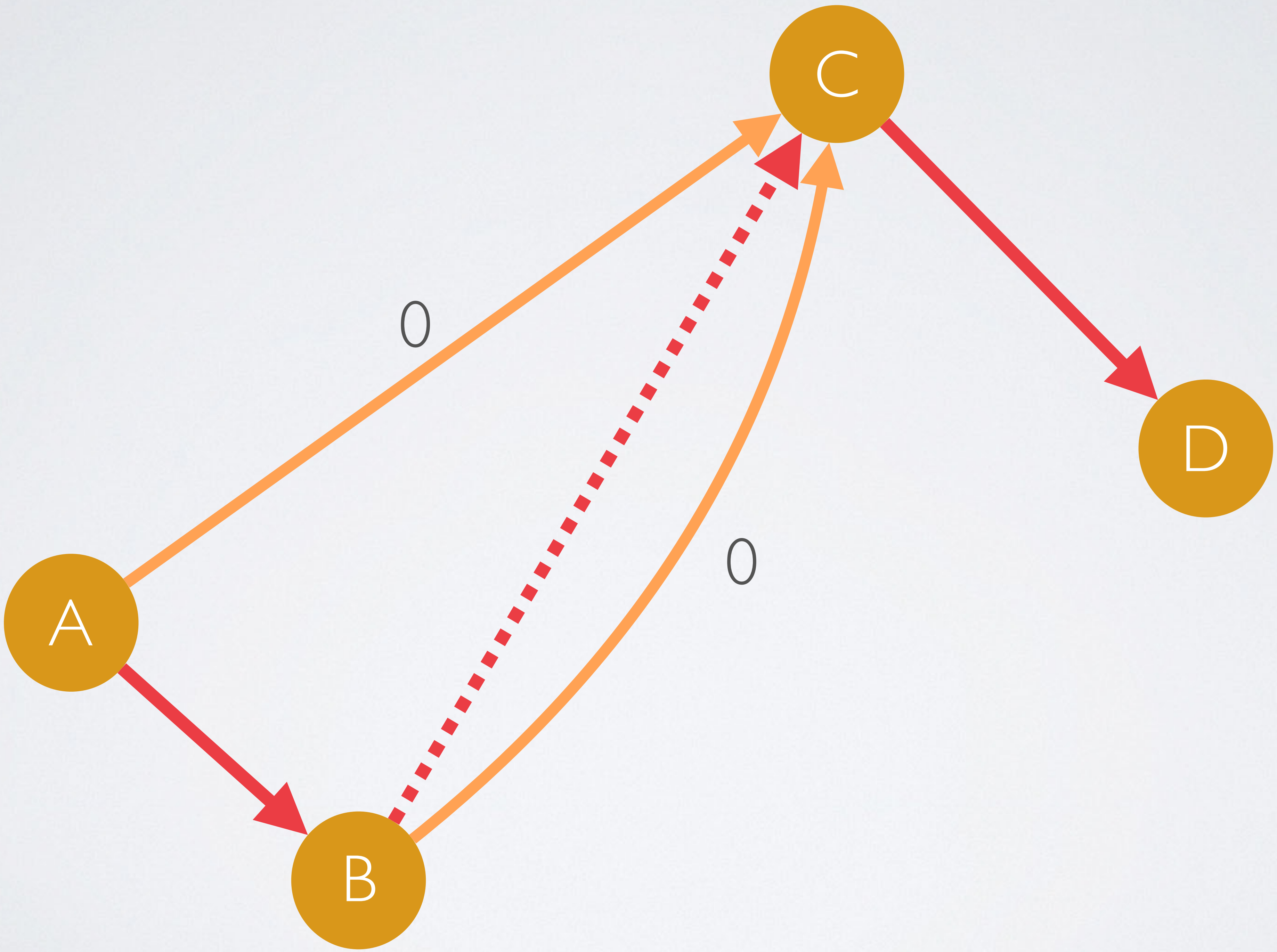
IDEA 3 : NETWORK WIDE FEATURES

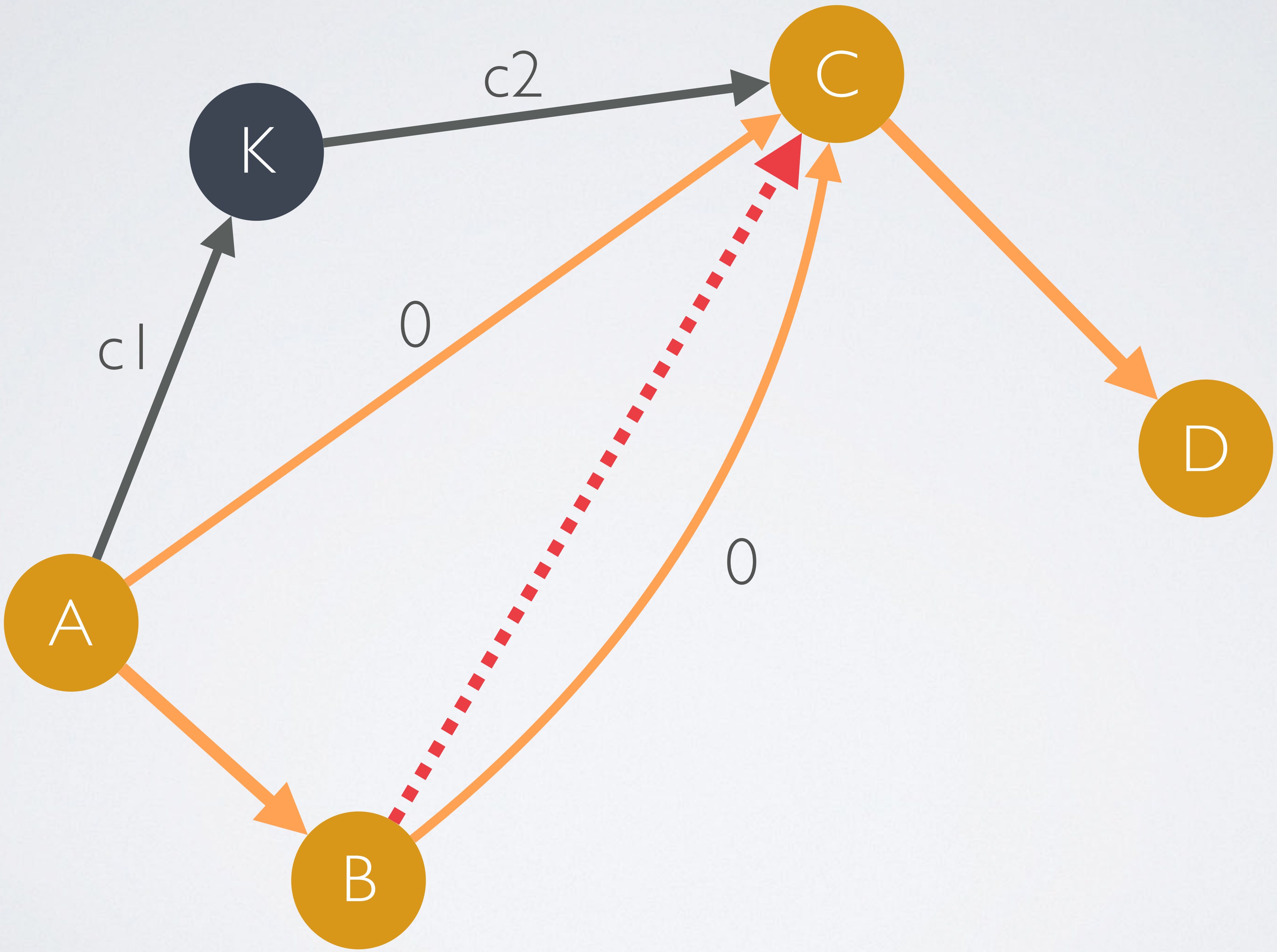
- Node2Vec Embeddings[1]
- Learn representations based on neighbors.

[1] Grover, A., & Leskovec, J. (2016, August). node2vec: Scalable feature learning for networks. In *Proceedings of the 22nd ACM SIGKDD international conference on Knowledge discovery and data mining* (pp. 855-864). ACM.

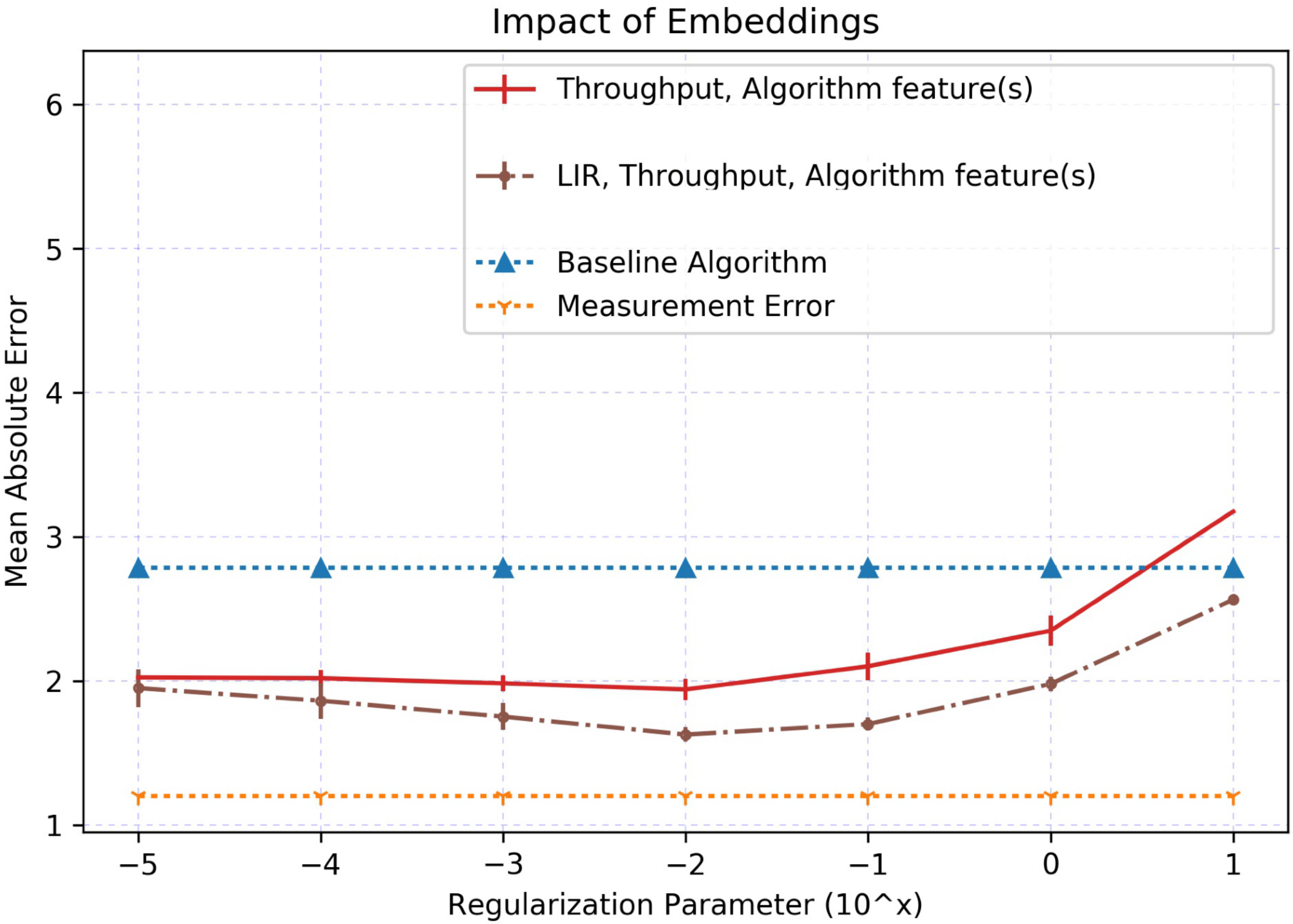
WHY IT MIGHT WORK



WHY IT MIGHT WORK

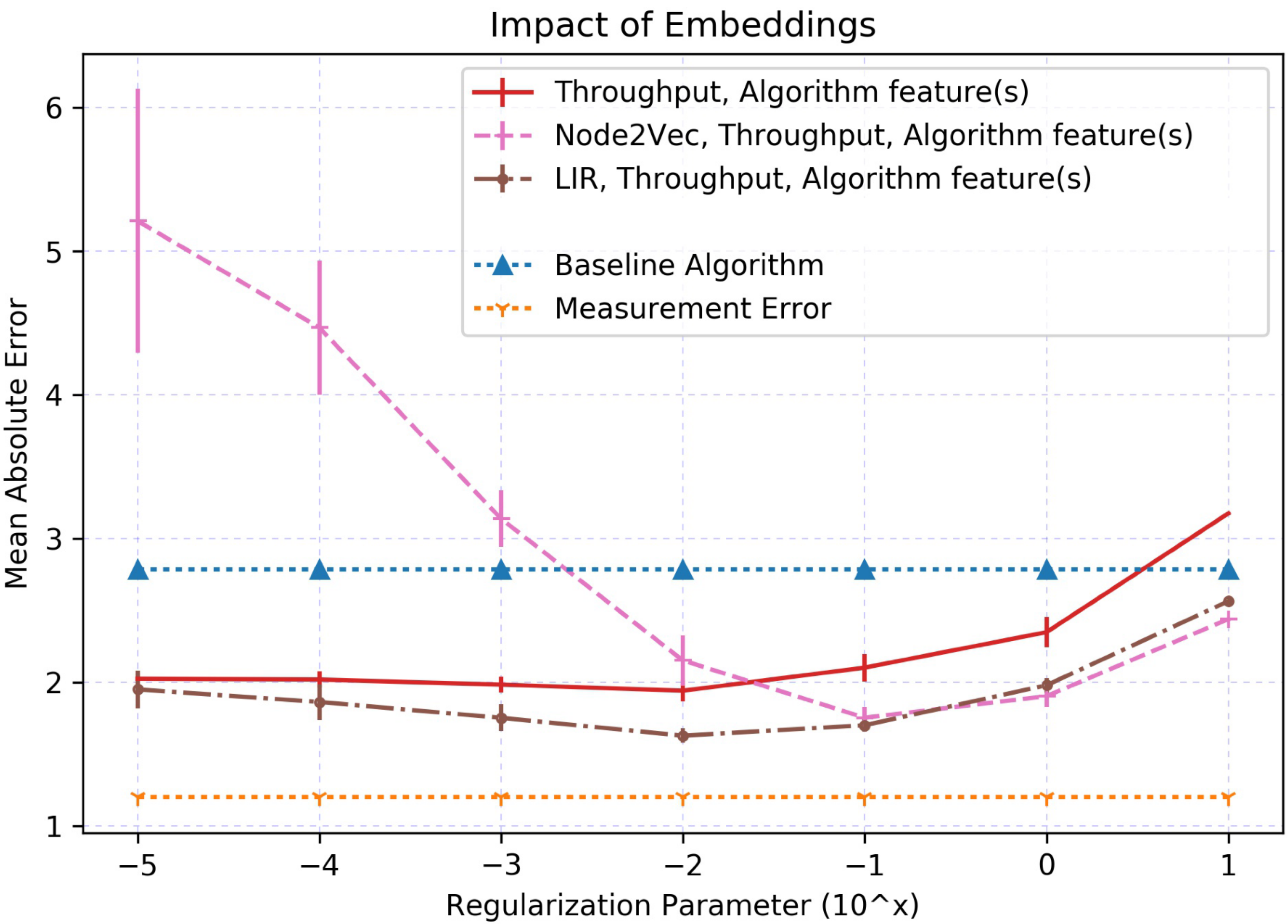


WPW Paths



Impact of Embeddings
Throughput, Algorithm feature(s)
LIR, Throughput, Algorithm feature(s)
Baseline Algorithm
Measurement Error
Mean Absolute Error
1
2
3
4
5
6
−5
−4
−3
−2
−1
0
1
Regularization Parameter (10^x)

WPW Paths



Impact of Embeddings
Throughput, Algorithm feature(s)
Node2Vec, Throughput, Algorithm feature(s)
LIR, Throughput, Algorithm feature(s)
Baseline Algorithm
Measurement Error
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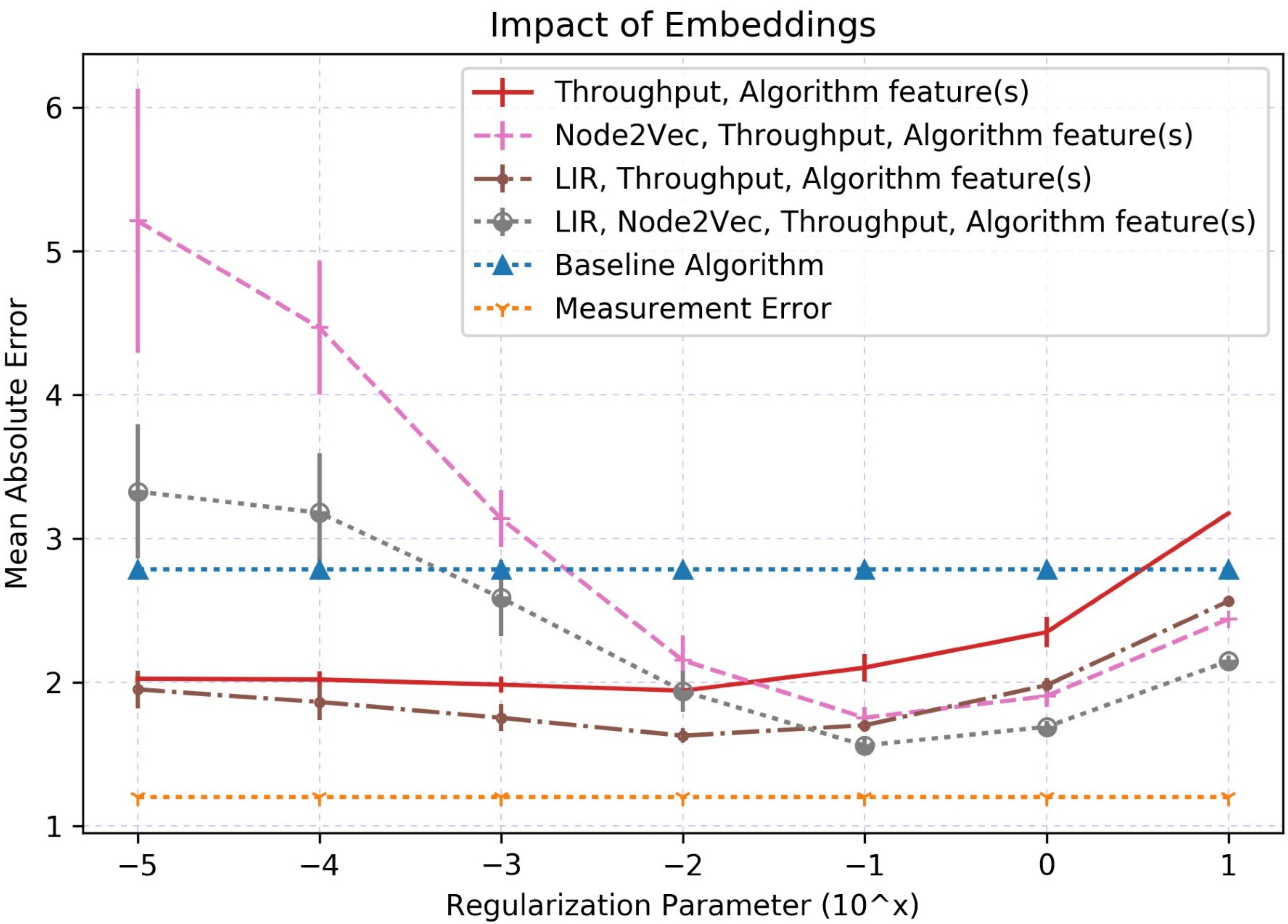
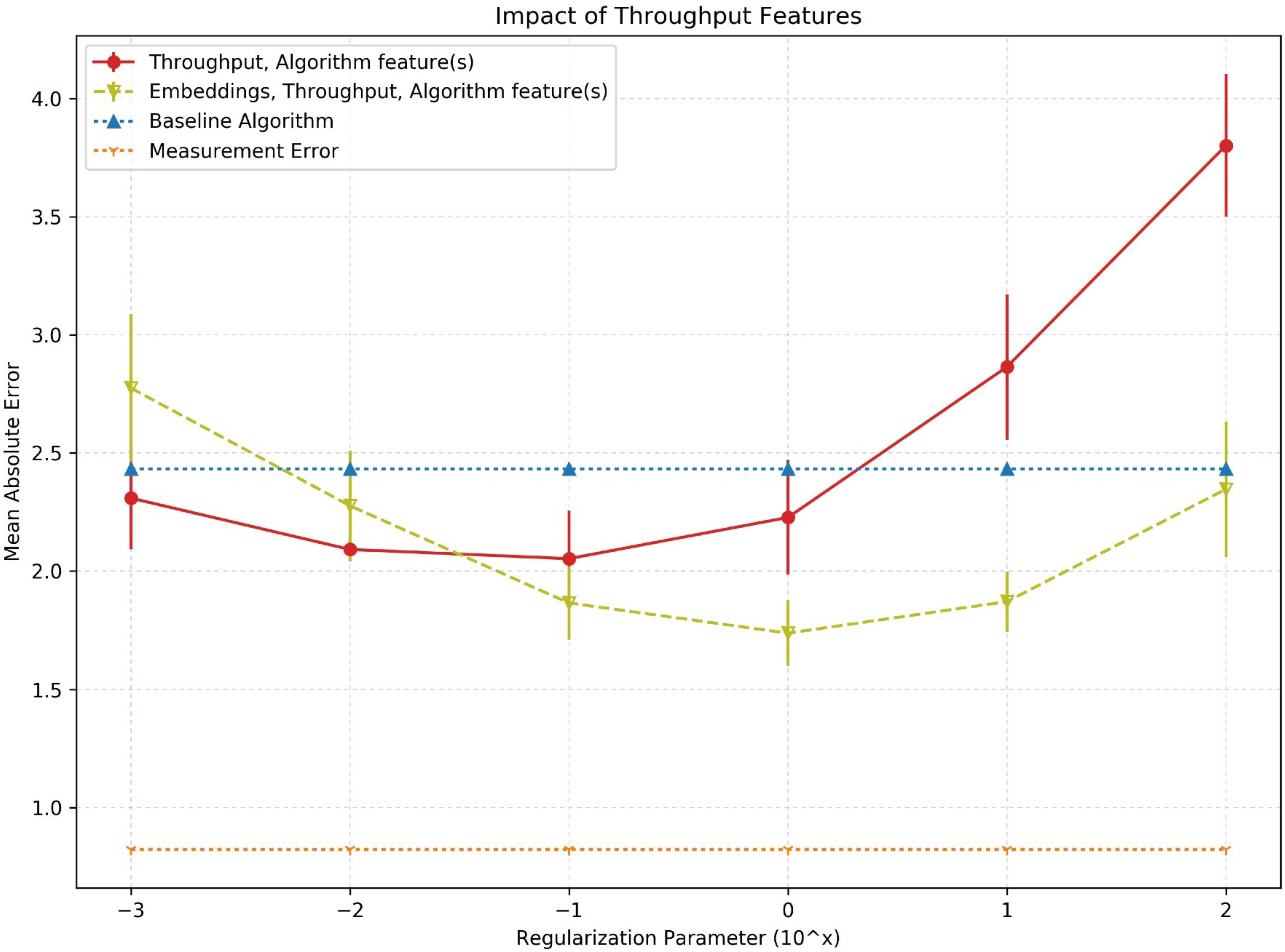
Regularization Parameter (10^x)
1
2
3
4
5
6
−5
−4
−3
−2
−1
0
1

WPW Paths



Impact of Embeddings
Throughput, Algorithm feature(s)
Node2Vec, Throughput, Algorithm feature(s)
LIR, Throughput, Algorithm feature(s)
LIR, Node2Vec, Throughput, Algorithm feature(s)
Baseline Algorithm
Measurement Error
Mean Absolute Error
1
2
3
4
5
6
−5
−4
−3
−2
−1
0
1
Regularization Parameter (10^x)

PWP Paths



Impact of Throughput Features
Throughput, Algorithm feature(s)
Embeddings, Throughput, Algorithm feature(s)
Baseline Algorithm
Measurement Error
Mean Absolute Error
4.0
3.5
3.0
2.5
2.0
1.5
1.0
−3
−2
−1
0
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CONCLUSIONS

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- LIR information is useful regardless of other features.
- Interference patterns of PLC and Wifi are not identical.
- We can learn from network-wide features.

FUTURE DIRECTIONS

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- Exploring network wide features more.

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- Understanding the reason behind differences in Wifi and PLC interference patterns.

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- Exploring network wide features more.
- Understanding the reason behind differences in Wifi and PLC interference patterns.
- Moving towards practical predictions.

FINAL REMARKS

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- Had an amazing summer.

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- Had an amazing summer.
- Visited great places and met awesome people.

FINAL REMARKS

- Had an amazing summer.
- Visited great places and met awesome people.
- It was not 40°C for a change.

QUESTIONS?

MODEL SELECTION

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- Input : Feature, Output : Path capacity
  - We collect data on a 22 node testbed using saturated UDP traffic.

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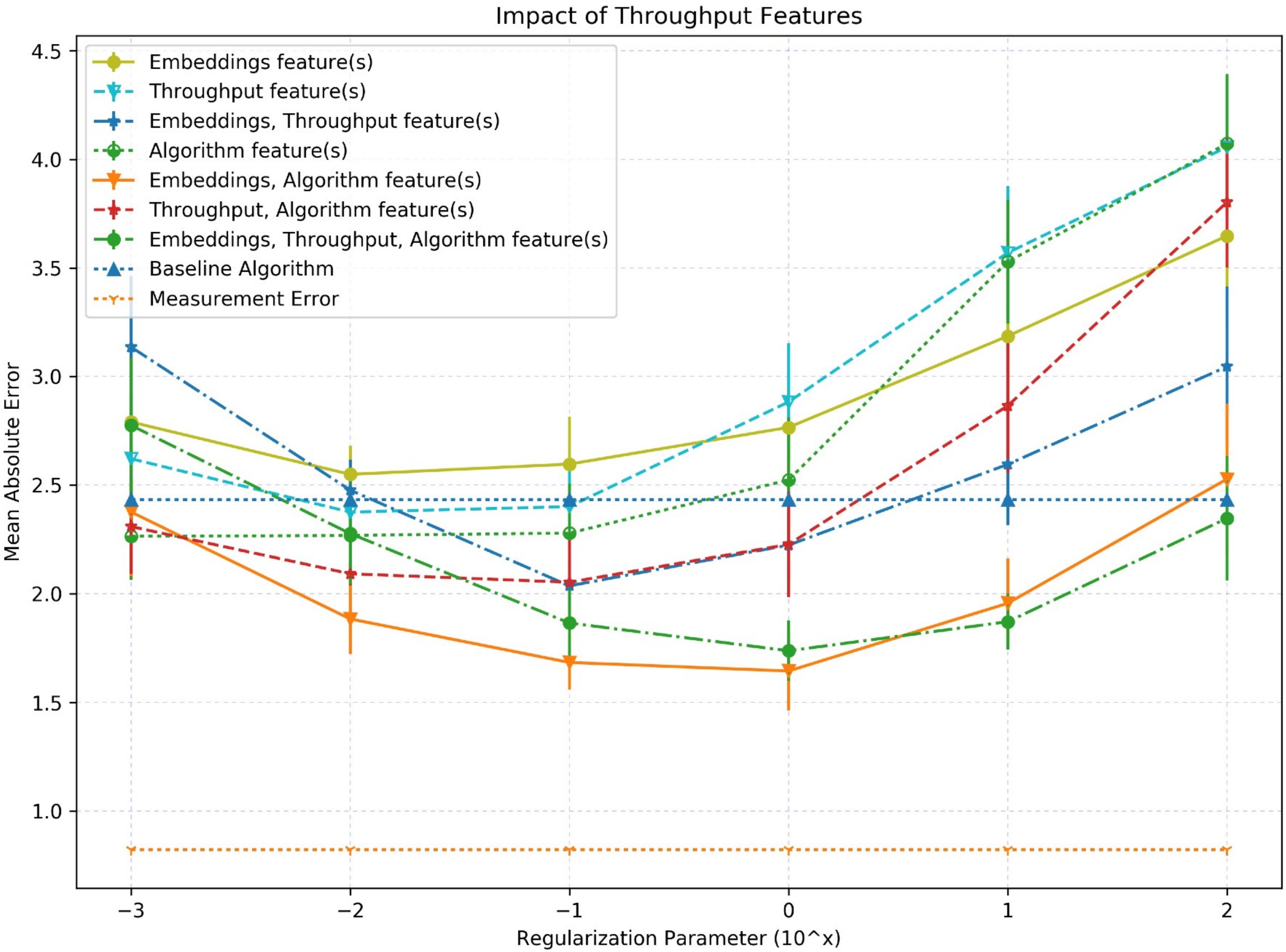
- Input : Feature, Output : Path capacity
  - We collect data on a 22 node testbed using saturated UDP traffic.
- Non-linear model to test usefulness of information.
  - Data augmentation by varying Wifi transmission power.
- Finding important features.
  - Achieving similar results as non-linear models using linear regression.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SOME INSIGHTS

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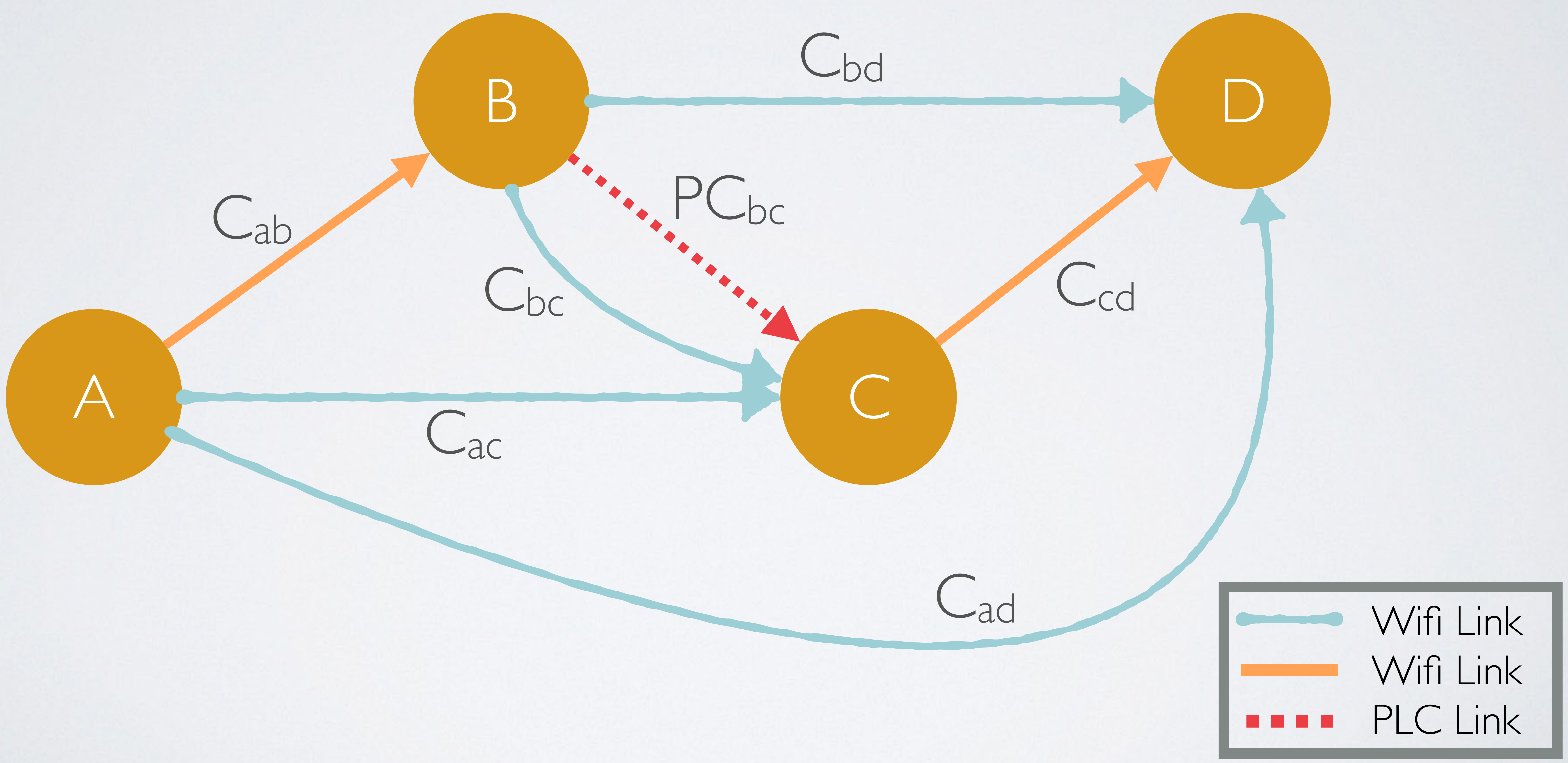
- Does the magnitude matter? Yes; to some extent.

IDEA 1 : USE LINK CAPACITIES



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- Does the magnitude matter? Yes; to some extent.
- Can we understand what the model learns? Yes.