Empirical Analysis of Transmission Power Control Algorithms for Wireless Sensor Networks

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Using Sensor Networks for Real World

- Industrial applications (e.g. HVAC, building control)
  - Using line-wiring for control and sensing.
  - WSN for low operating cost, deployment flexibility.
- Multi-hop routing is needed.
  - Span a long distance / No direct line of sight.
- Requirements:
  - Support high data throughput.
  - Consideration of limited resources of sensor networks.

An Idea: Adjusting Radio TX Power

- The radio transceiver of a sensor node is adjustable.
  - Increasing TX power: Reduces # of hops but increases interference.
  - Decreasing TX power: Increases # hops and chance of packet loss.
  - Increasing TX power to maximum doesn’t give optimum throughput.
- Idea: Adjust radio TX power for best possible throughput.
- Contribution of this work.
  - Performance analysis of radio transmission control algorithm on a real wireless sensor network testbed.

Related Work

- Some number of works tried to adjust radio transmission power for best possible performance.
- Limitations:
  - Based on Idealized simulators or hardware platforms without the same level of resource limitations of WSN.
  - Tested with only one multi-hop routing traffic pattern or single-hop.

Related Work (cont.)

Ramanathan *et al.*

Metrics	Throughput, transmission power, delay
Neighbors	Received-signal-strength based
Experiment	Simulation (Rooftop C++ Toolkit)
Traffic	Point-to-point routing between randomly chosen source-destination pairs

Kubisch *et al.*

Metrics	Network lifetime, connectivity
Neighbors	Connectivity based
Experiment	Simulation (OMNet++)
Traffic	Request/reply between two nodes using point-to-point routing

ElBatt *et al.*

Metrics	Throughput, transmission power
Neighbors	Received-signal-strength based
Experiment	Simulation (OPNET)
Traffic	Random point-to-point routing

Son *et al.*

Metrics	Packet reception rate (Throughput)
Neighbors	Packet-reception-rate based
Experiment	PC 104 nodes with Mica2 as radio transceiver
Traffic	Point-to-point routing using Directed Diffusion protocol between a sender and a receiver

Monks *et al.*

Metrics	Throughput
Neighbors	Received-signal-strength based
Experiment	Simulation (ns-2)
Traffic	Single-hop local communication

Ebert *et al.*

Metrics	Energy consumption, delay
Neighbors	Packet-reception-rate based
Experiment	Two laptops with wireless LAN
Traffic	Single-hop local communication

Wattenhofer *et al.*

Metrics	Coverage (# of neighbors)
Neighbors	Connectivity, angle-of-arrival (AOA)
Experiment	Simulation (ns-2 based on WaveLAN-I radio)

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- Description of transmission power control algorithm
- Traffic patterns for wireless sensor networks
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- Experiment Results
  - Convergence Traffic
  - Aggregation Traffic
  - Comparison of convergence / aggregation traffics
- Conclusion

Description of Transmission Power Control Algorithm

- TX Power control algorithm steps:

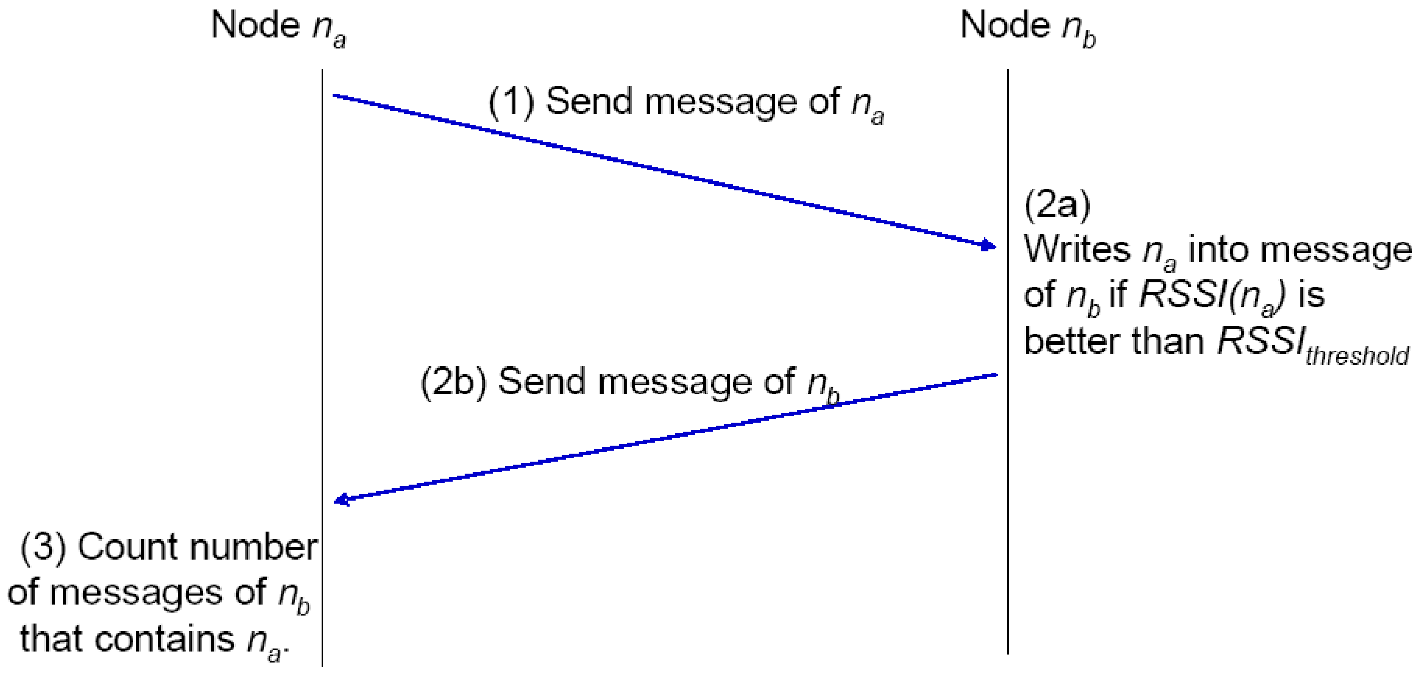
1) Count the number of neighbors.
   - Approximation for the throughput
2) Adjust the radio-transmission of the sensor node so that # of neighbors stays within the desired range.

Metrics for choosing neighbors

- Connectivity
  - Does not filter the nodes of bad link quality.
- Packet Reception Rate (PRR)
  - Filter the neighbors based on PRR.
  - Does not require hardware support.
  - Overhead of maintaining neighbor table.
- Received Signal Strength.
  - Filter the neighbors based on received signal strength.
  - With hardware assistance, it can determine link quality with little software overhead.
- We use received signal strength based methods.

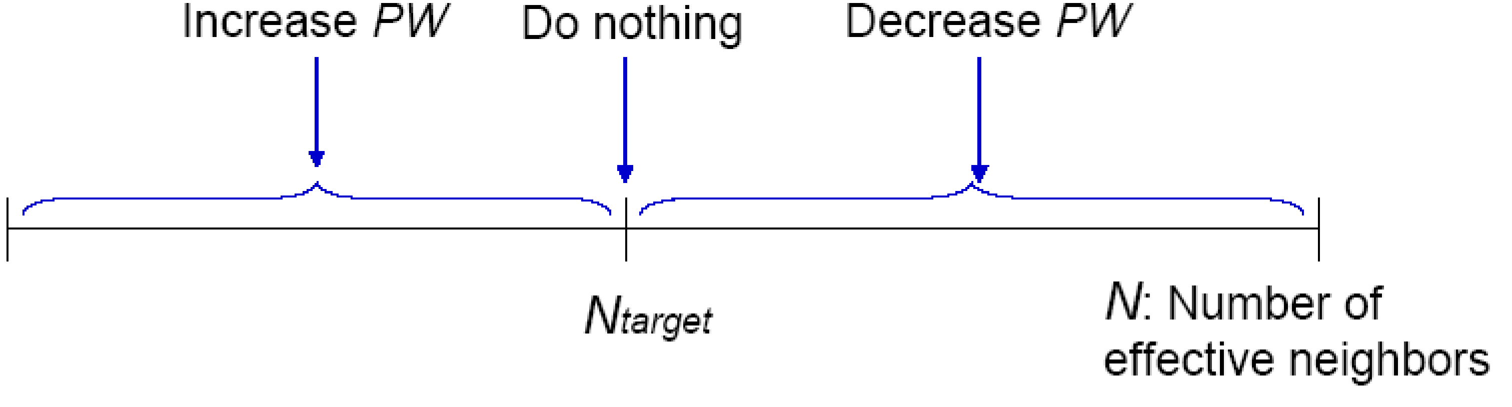
Finding number of effective neighbors

- Node n_a sends a beacon.
- Node n_a counts how many neighboring nodes have heard the node.



Adjusting radio-transmission power

- Binary search like power control algorithm.
  - Increase or decrease TX power depending on #Nbrs is smaller or larger than N_{target}.
  - Divide the increment by half when direction changes.



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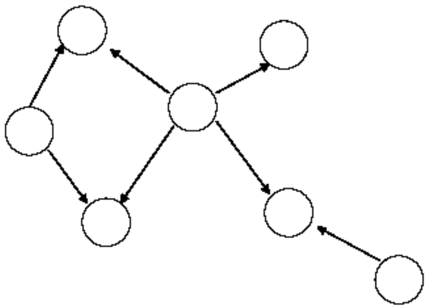
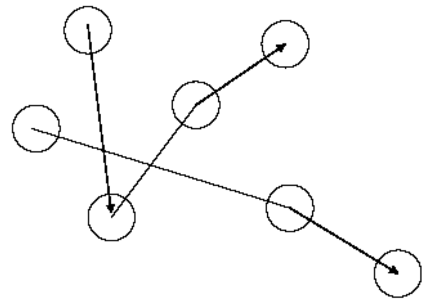
Traffic Patterns in Sensor Networks



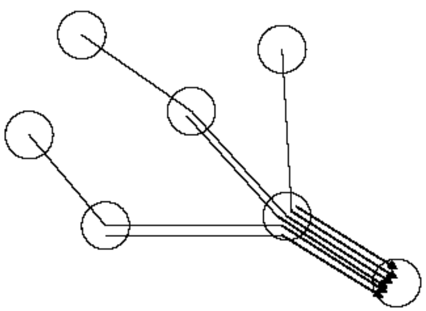
(a) Local Communication

- Single-hop
- Broadcast status to neighbors.



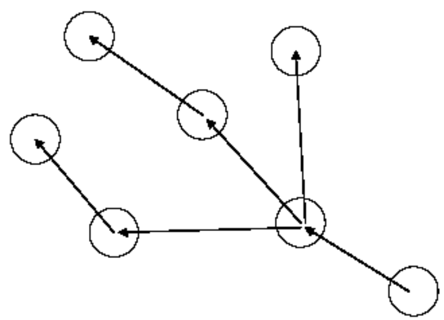
(b) Point-to-point

- Send data packet from an arbitrary node to another.
- Common in Wireless LAN



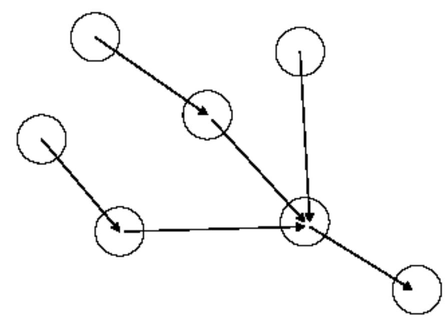
(c) Convergence

- Many-to-one
- Used for data collection in WSN.



(d) Divergence

- One-to-many
- Used for sending command in WSN.



(e) Aggregation

- Many-to-one
- In-network processing.

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Experimental Methodology - Platform

- We used Smote testbed (based on Mica2dot).
  - Monitor the behavior of a real sensor network.
  - 22 sensor nodes including base node.
  - TinyOS MintRoute for multi-hop routing.

(a) A Smote node

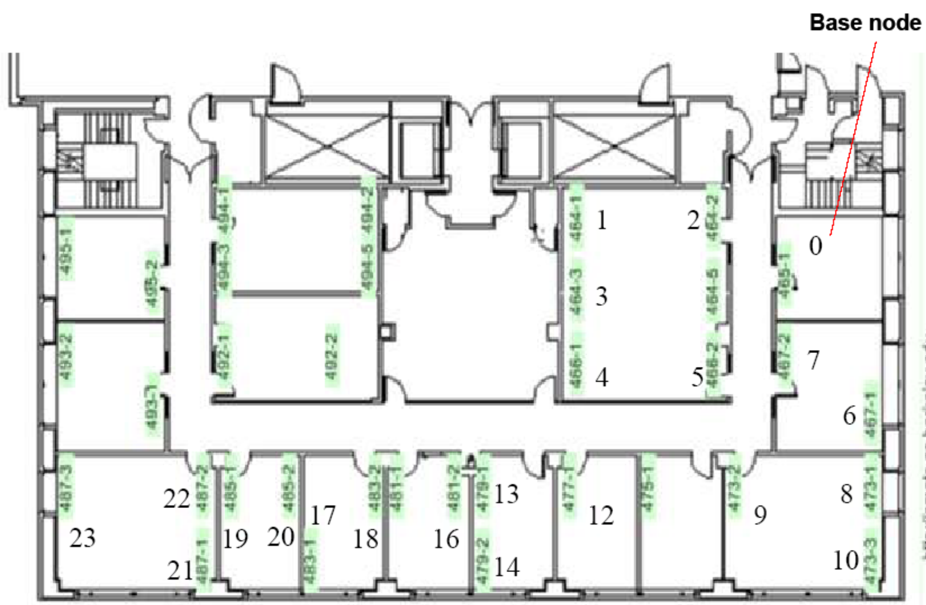

Fig. 5. Node Layout for experiments

Experimental Methodology - Performance Metrics

- Throughput: *how much traffic a sensor network can handle?*
  - Throughput for end-to-end traffic (from node *i* to base node).

$$\text{Per-node throughput for } i = \frac{nPackets(i)}{Duration}$$

  - Fairness index for the throughput

$$f(x_1, x_2, \cdots, x_n) = \frac{(\sum_{i=1}^{n} x_i)^2}{n \sum_{i=1}^{n} x_i^2}$$

Experimental Methodology
- Performance Metrics (cont.)

- Approximating Energy Consumption
  - The energy E_k for sensor node *k* is $E_k = I \cdot V \cdot t \cdot M$
    - I: current draw of a Mica2dot transceiver (lookup table)
    - V: supply voltage
    - t: packet transmission time.
    - M: # messages a sensor node has originated or forwarded.
  - We can compare Energy Cost = $I \cdot M$ for energy consumption.
    - V and t are assumed to be the same for all the sensor nodes.

Experimental Methodology - Performance Metrics (cont.)

- Neighbor distribution:
  - How does algorithm adapt to an optimum state for different initial parameters?
- Routing Status:
  - How are messages routed?
  - Why does a certain network conf. perform better or worse?
- Traffic Reduction for Aggregation Traffic:
  - How much traffic does aggregation reduce?
  - We measure traffic going into base / originating traffic.

Experiment Results
- Experiment Configurations

- Common Setting:
  - Data sending rate: 1 packet per every 2 seconds.
  - Measurement time: 20 minutes per each run.
- For the fixed transmission-power-control algorithm (FIXED):
  - Set the transmission power of all the nodes to PW_{init}
  - PW_{init}: 64, 128, 192, 255
- For dynamic transmission-power-control algorithm (DYNAMIC):
  - Each node adjusts its transmission power with the parameters:
  - N_{target}: 3,6,9,12,15
  - $RSSI_{threshold}$: 50

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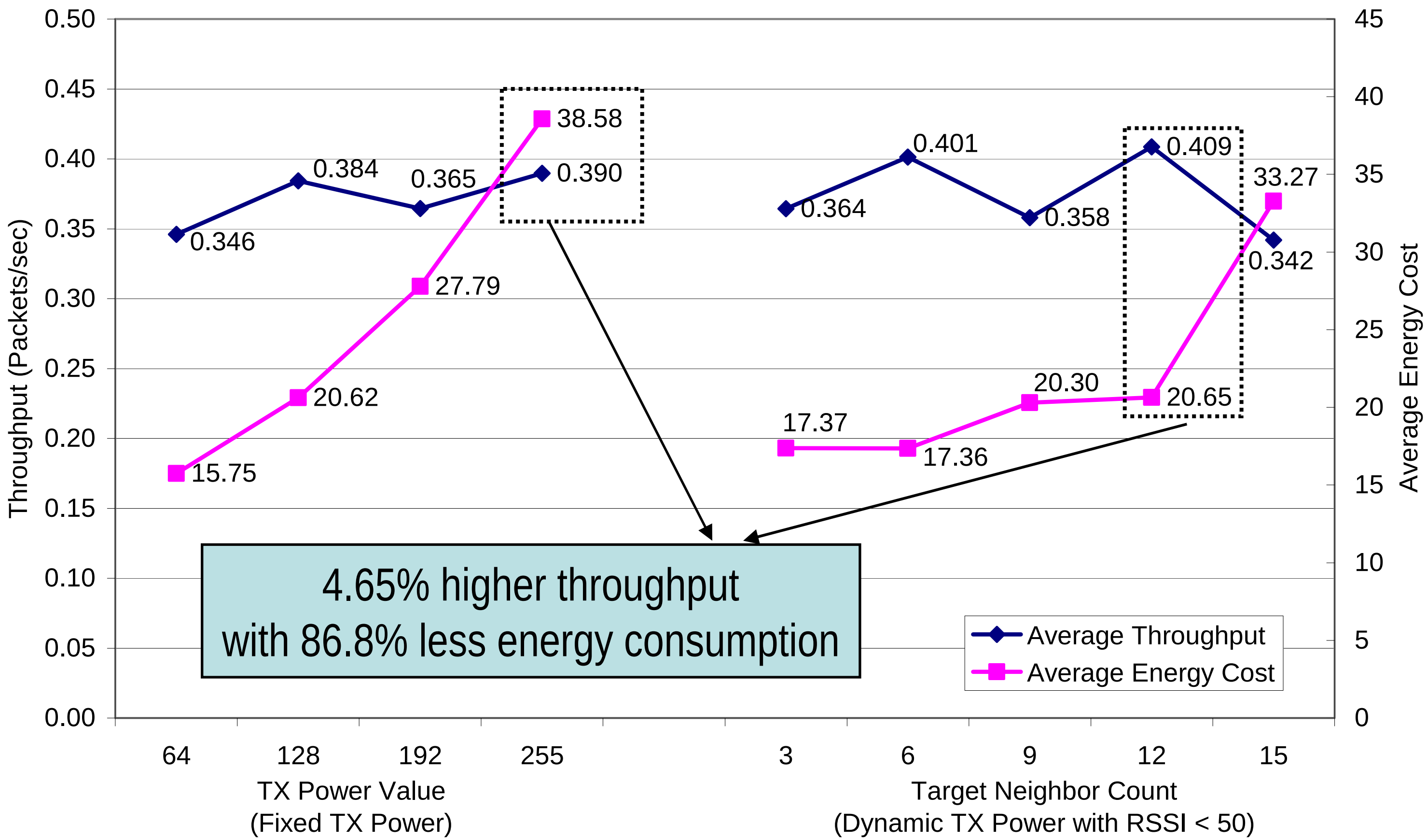
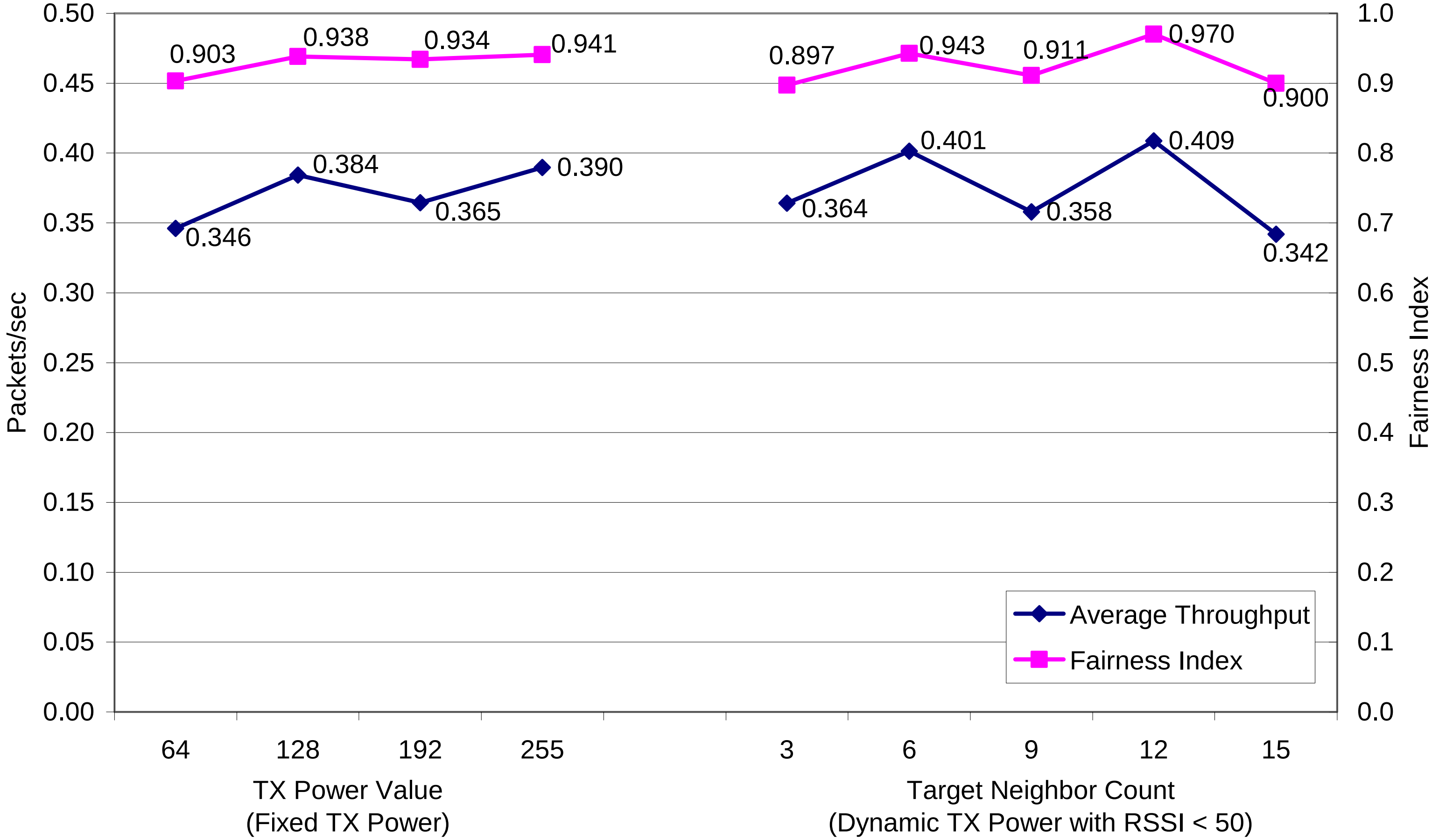
Convergence Results
- Throughput and Energy Consumption

- DYNAMIC does not improve the throughput itself very much over FIXED.
- DYNAMIC achieves high throughput with much less energy consumption.



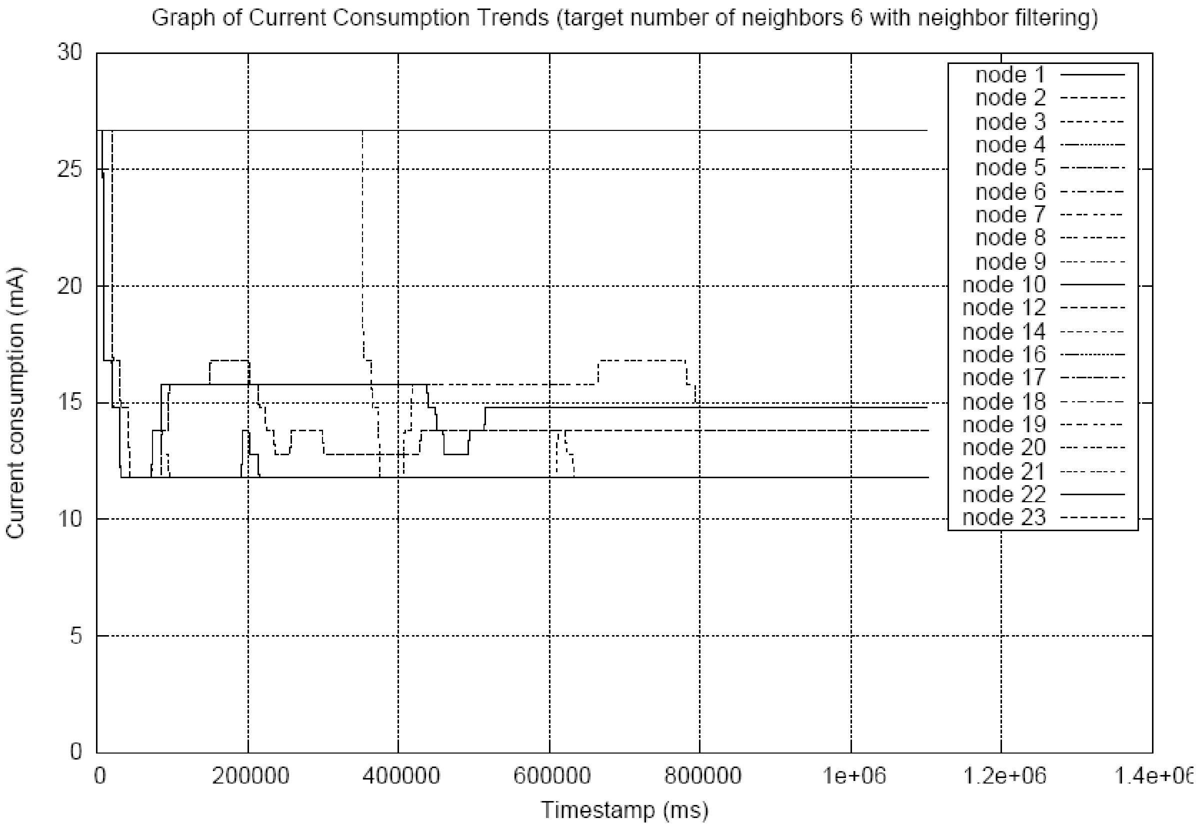
Convergence Results
- Throughput and Fairness Index

- Maximum fairness index at the point of maximum throughput.
- DYNAMIC had better fairness index than FIXED.



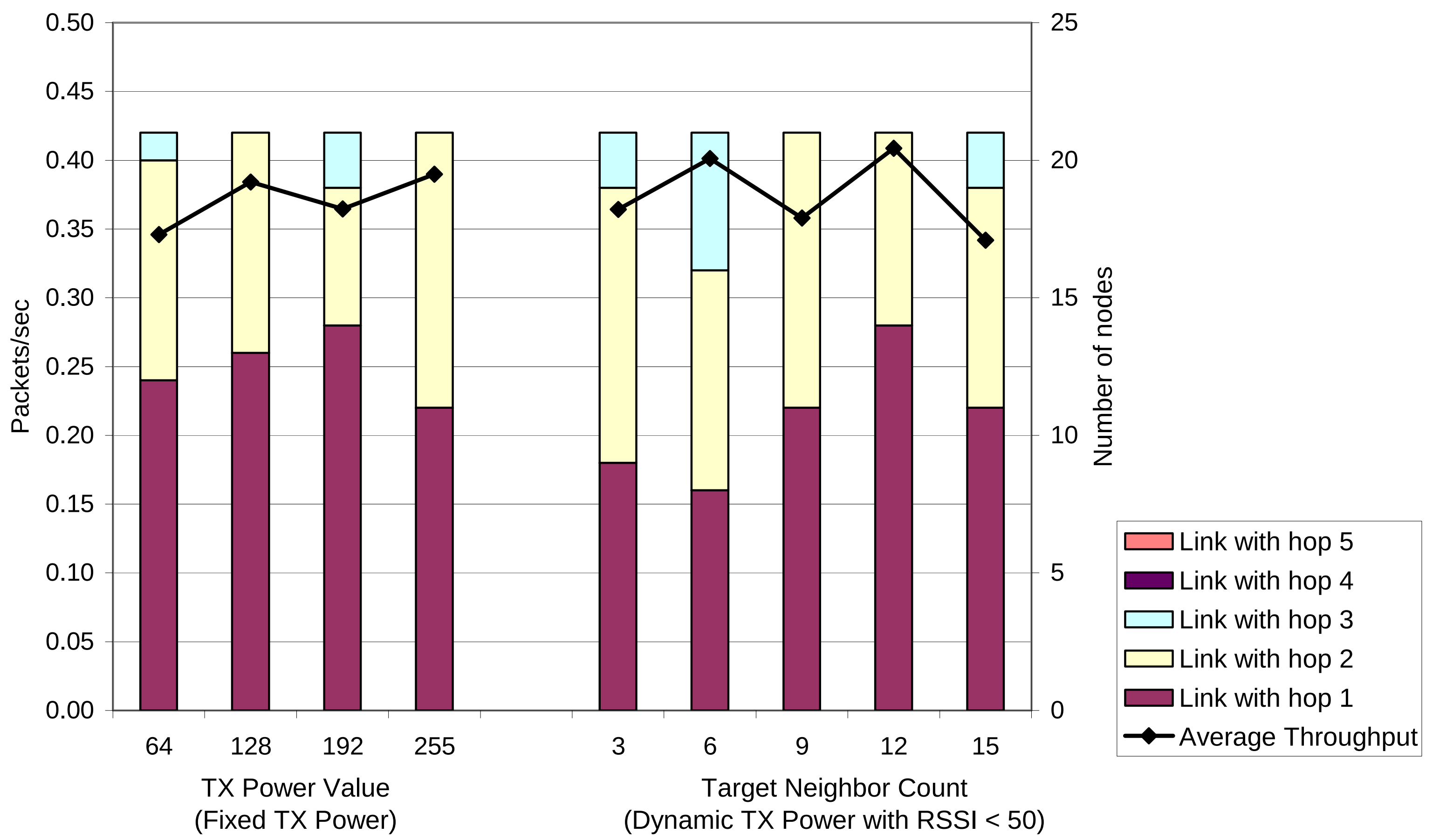
Convergence Results
- Current Consumption Trends

- Each node converges to point where # of nbrs is closest to N_{target}.
- Some nodes don't have desired number of neighbors.
  - Either at maximum TX power or the minimum TX power.



Convergence Results
- Number of hops and routing status

- Hop count itself doesn't tell which configuration is better.
- Throughput at each hop gives more information.



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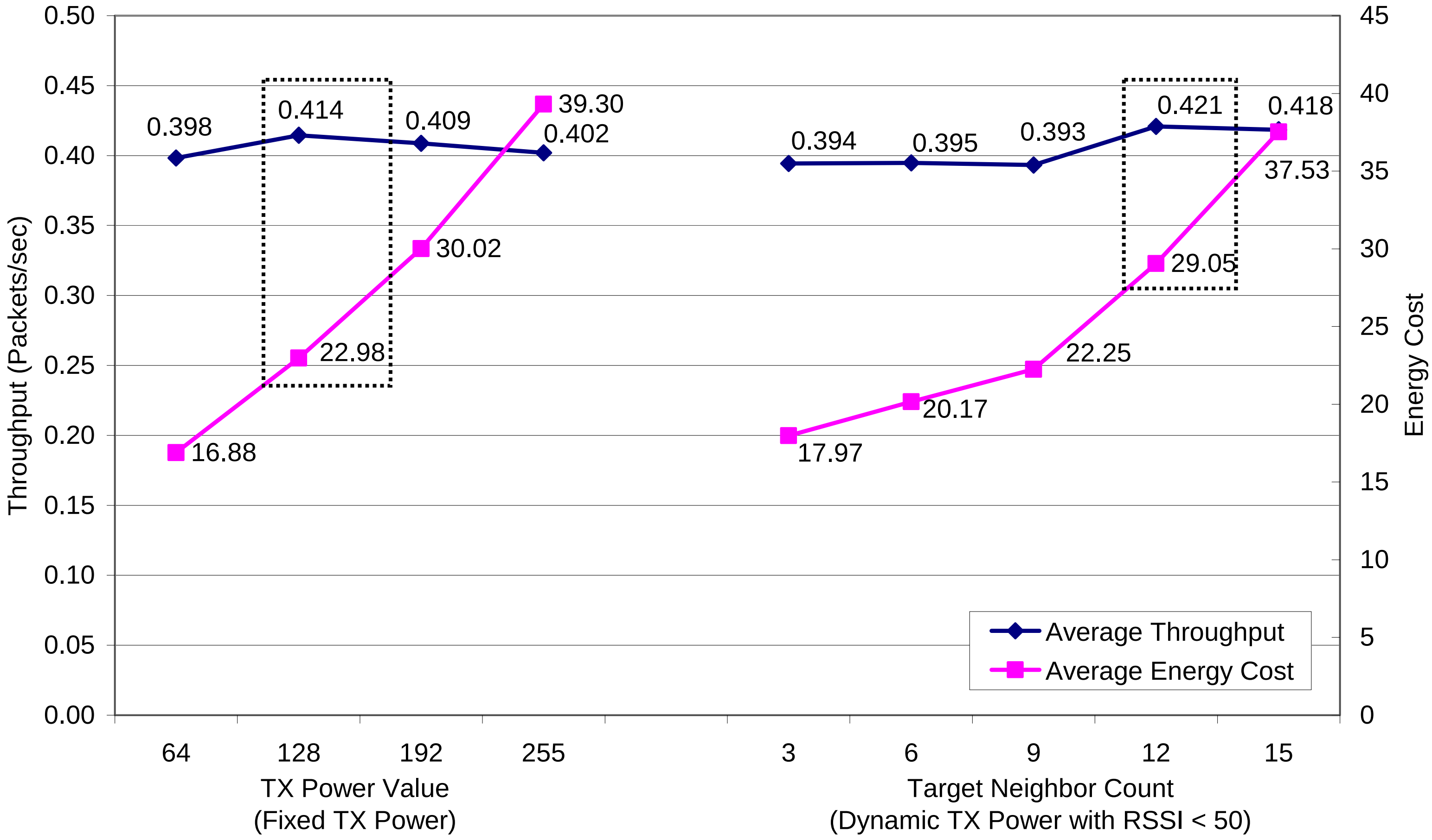
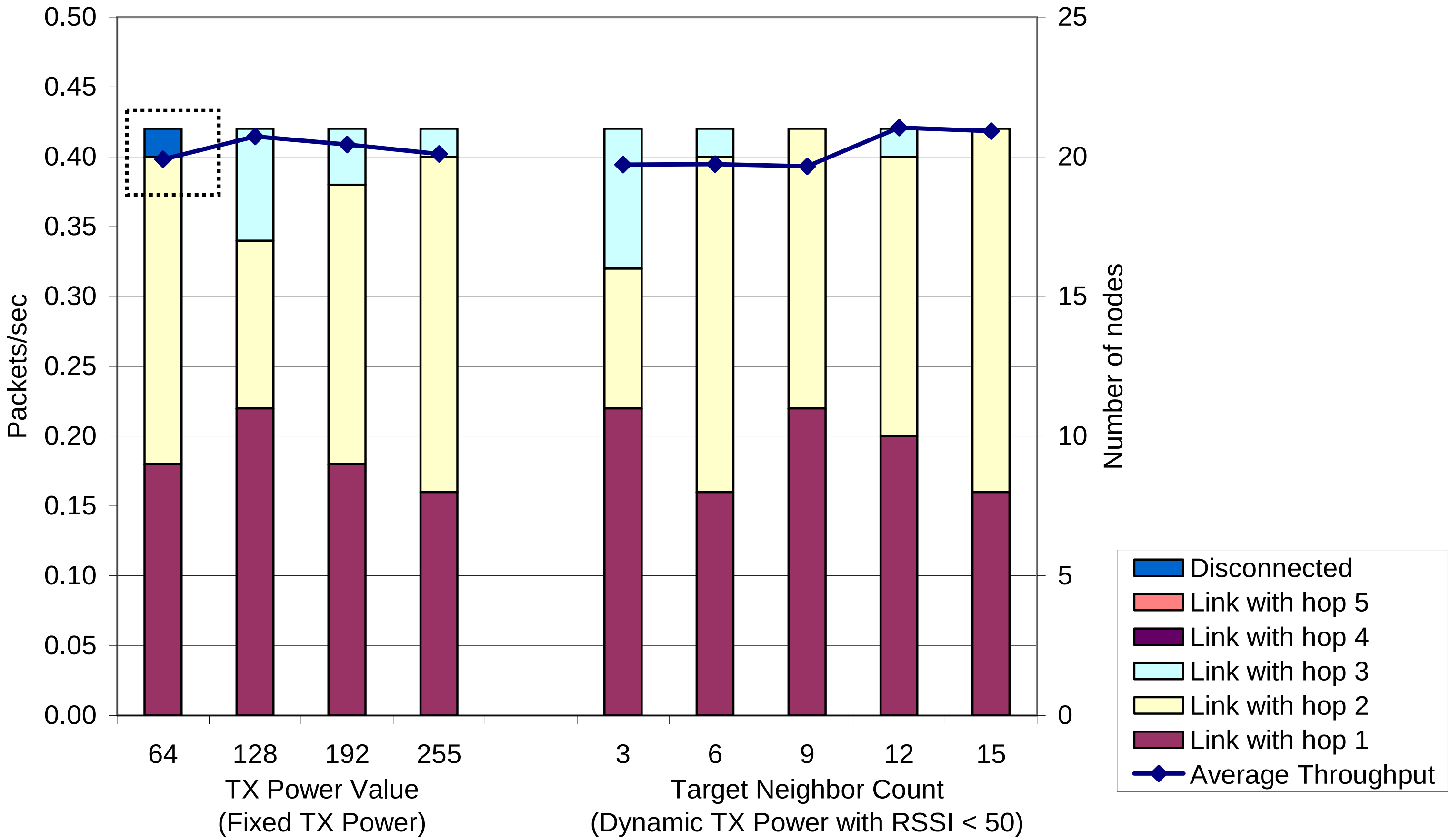
Aggregation Results
- Throughput and Energy Consumption

- DYNAMIC does not have the same performance improvement compared to FIXED when applied to the aggregation traffic pattern.



Aggregation Results
- Throughput and number of hops

- FIXED has a disconnected node at PW = 64.
- This is because FIXED does not set the radio-transmission power of the node large enough to be heard by other nodes.



Comparison of convergence and aggregation traffics

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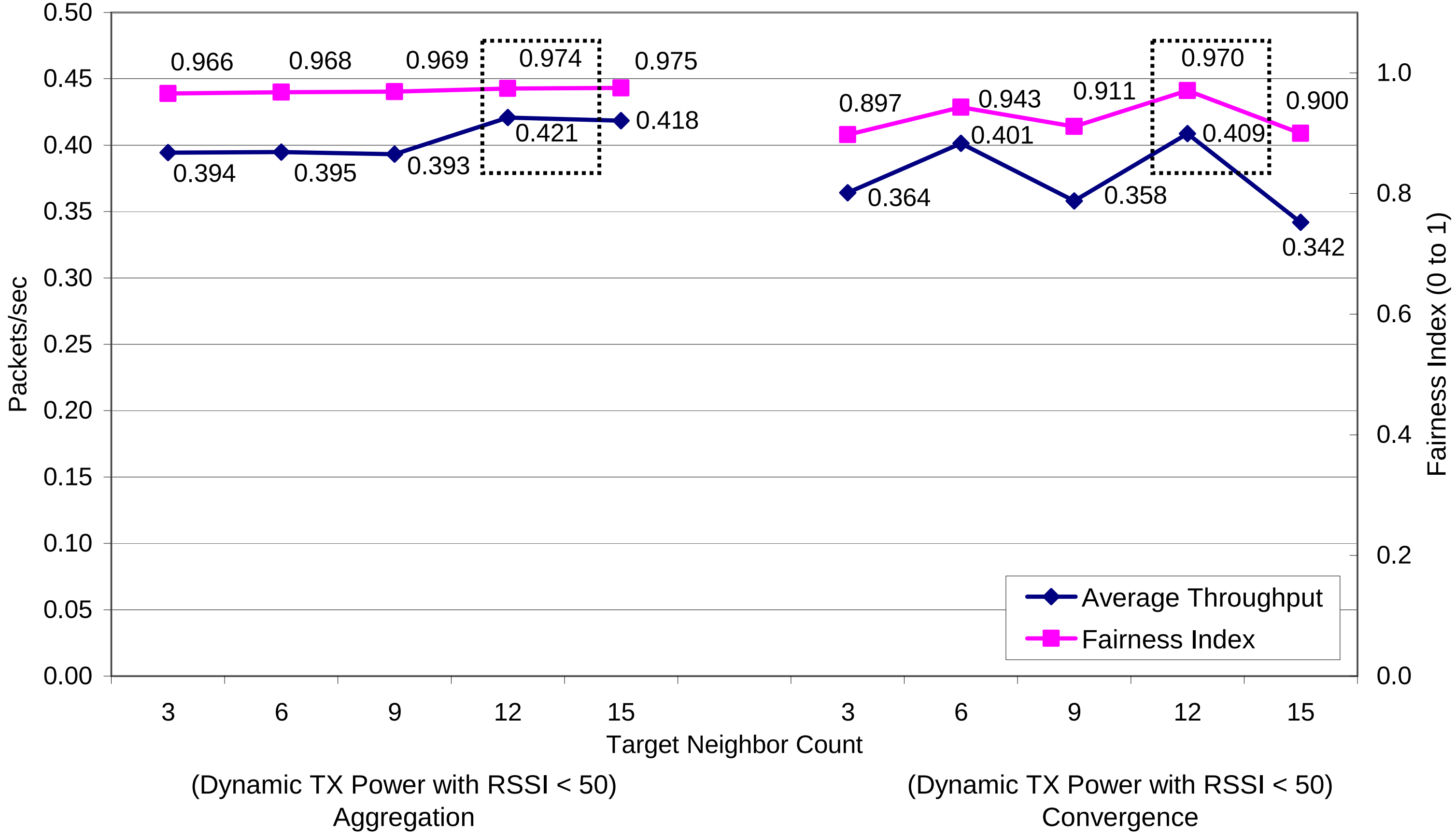
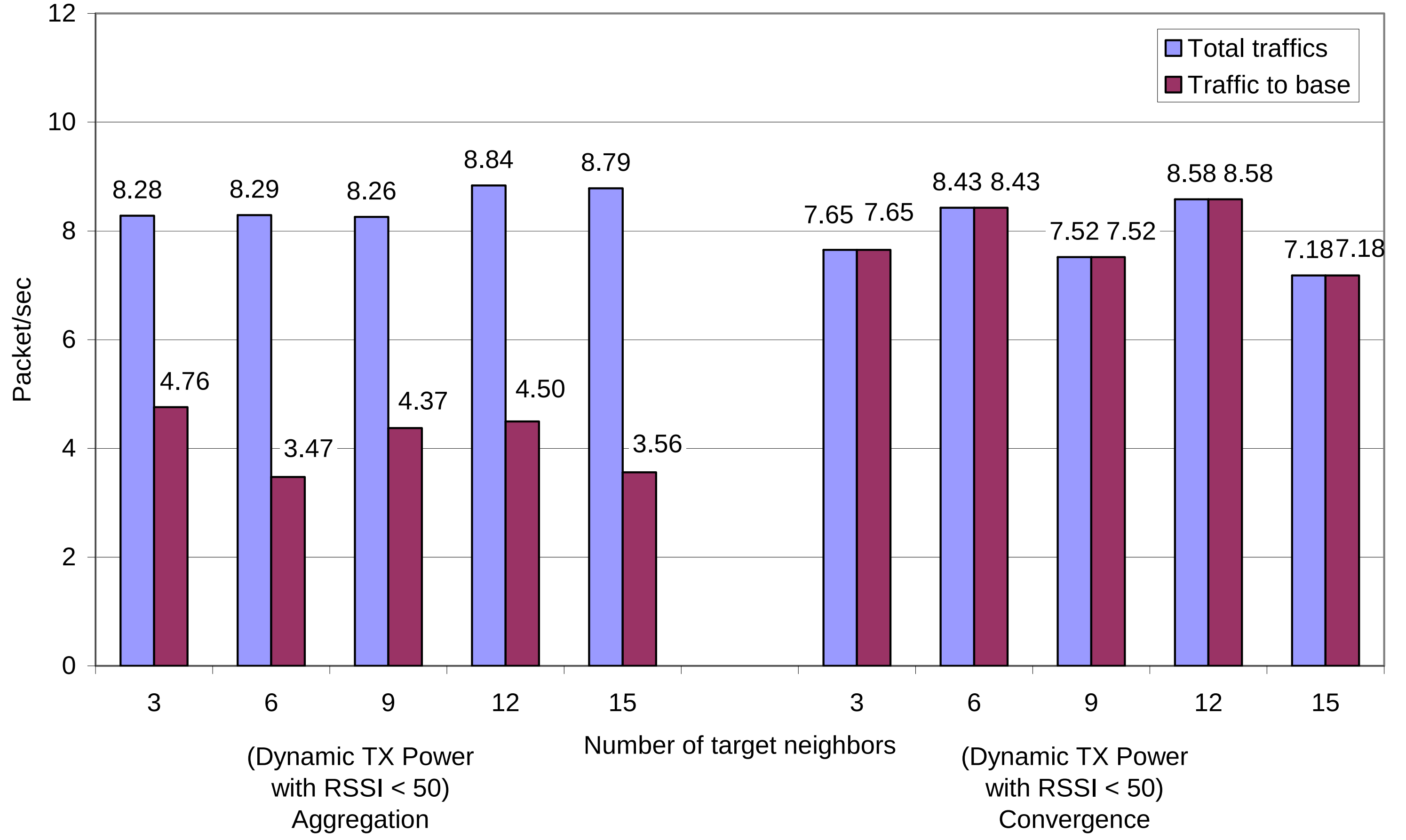
Comparison of convergence and aggregation - Throughput and Fairness Index

- DYNAMIC achieves higher throughput and higher fairness with the aggregation traffic than with the convergence traffic.



Comparison of convergence and aggregation - Total traffic and traffic to the base

- With convergence traffic pattern, all originating traffic goes into base.
- With aggregation traffic pattern, the traffic going into base is reduced to 40.5% to 57.5% of the originating traffic.



Conclusion

- Contributions
  - Performance analysis of radio TX power control algorithm.
    - Using Mica2dot-based WSN testbed Smote
    - For convergence and aggregation traffic patterns
- Findings
  - Convergence traffic pattern:
    - DYNAMIC makes little difference to throughput while it saves energy consumption over FIXED.
  - Aggregation traffic pattern:
    - Higher end-to-end throughput and fairness than convergence.

BACKUP SLIDES

Convergence Results
- Number of hops and routing status (cont.)

Throughput per hop (FIXED)

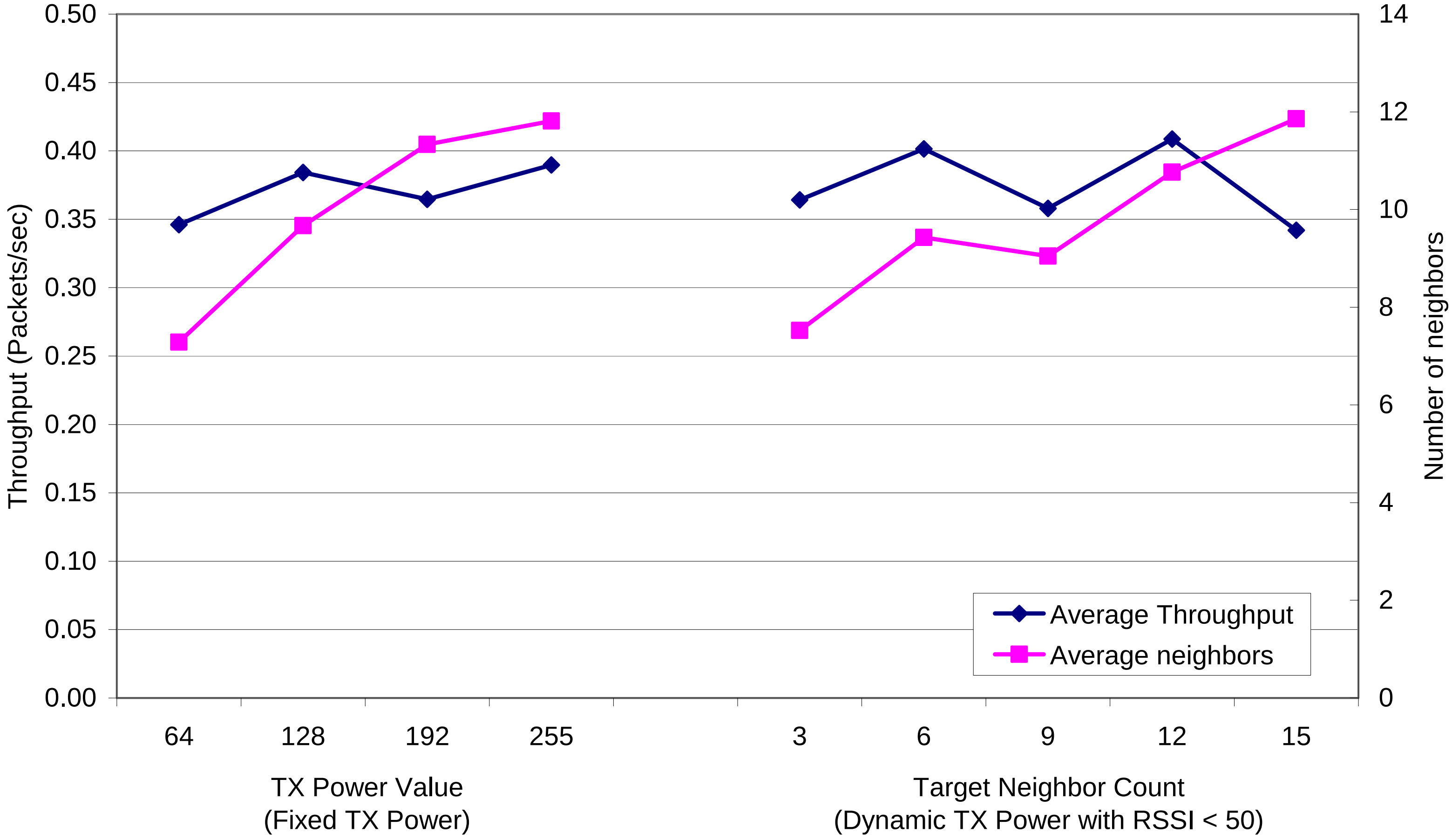
PW	64	128	192	255
Average	0.346	0.384	0.365	0.390
Hop 1	0.405	0.432	0.342	0.436
Hop 2	0.287	0.306	0.423	0.339
Hop 3	0.105	-	0.376	-
Hop 4 or more	-	-	-	-

Throughput per hop (DYNAMIC)

N_{target}	3	6	9	12	15
Average	0.364	0.401	0.358	0.409	0.342
Hop 1	0.416	0.427	0.414	0.417	0.359
Hop 2	0.351	0.379	0.296	0.393	0.362
Hop 3	0.197	0.396	-	-	0.167
Hop 4 or more	-	-	-	-	-

Convergence Results
- Throughput and number of neighbors

- Number neighbors tends to increase as N_{target} increases.



Aggregation Results
- Throughput and number of neighbors

- Number of neighbors increases as we increase the number of target neighbors N_{target}.