Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Simulation Results for Final Proposal 15-3-0380]
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Re: [Simulation Results for Final Proposal]

Abstract: [This document presents simulation results on the MAC system design for 802.15.8 (PAC)]

Purpose: [To discuss performance of proposed system design for 802.15.8 (PAC)]

Content

1. Performance of Discovery Procedure
2. Performance of Peering (Association) Procedure
3. Performance of Data Communication
4. References

– All the technique details in this presentation can be found in the final proposal [2]: “IEEE-15-13-0380-02-0008”

1. Performance of Discovery Procedure

Terms and Concepts--Discovery

- Peer Device (PD): A PAC device
- Tx PD: a PD that keeps sending discovery frames (i.e., beacon or repeated discovery request) within the proximity to be discovered
- Rx PD: a PD that is configured with a Tx PD, and keeps scanning the discovery frames to discover the desired Tx PD.
- To discover: A Rx PD scans discovery frames to find the desired Tx PD.
- To be discovered: A Tx PD sends out discovery frames to be discovered by a Rx PD within the proximity.

Background--Discovery

- Discovery Schemes
  - Beacon based discovery:
    - A Tx PD sends beacon at beginning of its application frame to be discovered.
  - Discovery request based discovery:
    - A Tx PD sends “to be discovered” request once or multiple times after beacon in its application frame.
- Channel Management Scheme
  - Contend for accessing the common channel (i.e. CCDCH) for channel allocation request.
  - Insert application frame at the allocated location within a superframe.
- Topology Generation
  - Follow the 2-step procedure in the TGD
    - Drop Tx PD first, and then randomly drop Rx PDs within 50 meters of each Tx PD.

Simulation Scenarios--Discovery

- Scenario 1: “to discover” scenario
  1. All Tx PDs are turned on at time 0 and start contention based channel allocation request.
  2. Then, all Tx PDs send beacon or “to be discovered” request on the allocated channel.
  3. Then, all Rx PDs are randomly turned on.
- Scenario 2: “to be discovered” scenario
  1. All Rx PDs are turned on at time 0.
  2. Then, all Tx PDs are randomly turned on from time 0 and start contention based channel allocation request.
  3. Then, all Tx PDs send beacon or “to be discovered” request on the allocated channel.

Simulation Configuration Set 1--Discovery

- For the cases of 100, 500, 1000 PDs, there are 5, 10, 20 Tx PDs respectively.

Parameter	Value
Slot size	1 ms
CCDCH length	10 ms (10 slots)
Number of Superframes	100
Superframe length	120 ms (120 slots)
Simulation time	Number of Superframe * Superframe length * Slot size = 12 seconds
Beacon interval	1 * Superframe length
Application frame length	5 ms (5 slots)
Bandwidth	10 MHz
Channel data rate	3 Mbps
General parameters	TGD revision 7 [1]

Simulation Configuration Set 2--Discovery

- For the case of 5000 PDs, there are 50, 100, 200, …,500, 1000 Tx PDs.

Parameter	Value
Slot size	1 ms
CCDCH length	20 ms (20 slots)
Number of Superframes	30
Superframe length	320 ms (320 slots)
Simulation time	Number of Superframe * Superframe length * Slot size = 9.6 seconds
Beacon interval	1 * Superframe length
Application frame length	5 ms (5 slots)
Bandwidth	10 MHz
General parameters	TGD revision 7 [1]
Channel data rate	3 Mbps

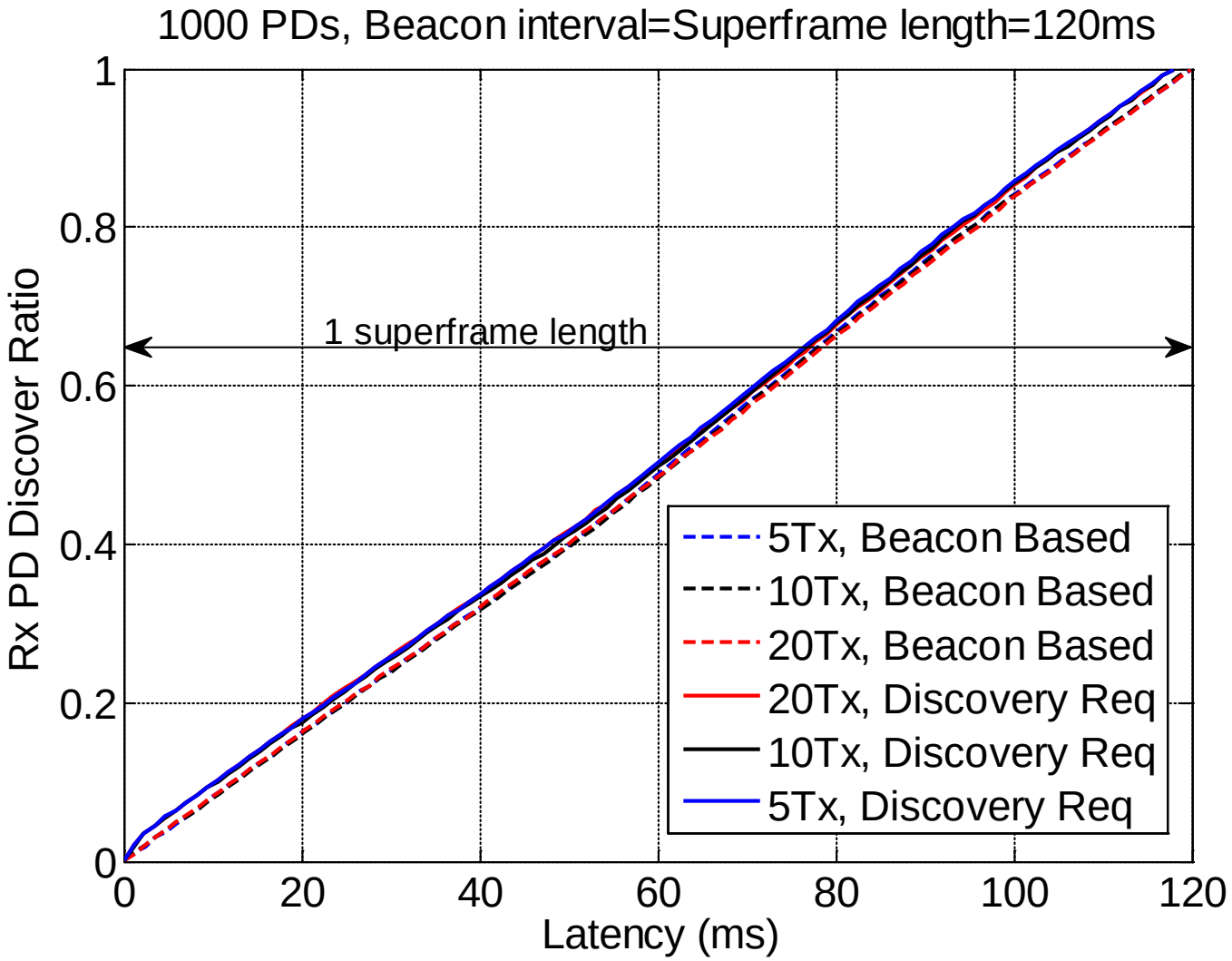
Discovery Performance Metrics

- Discovery latency
  - "to discover" latency (measured in scenario 1):
    - This metric is determined from the time that a Rx PD is turned on to the time that the Rx PD discovers the desired Tx PD.
  - "to be discovered" latency (measured in scenario 2)
    - This metric is determined from the time that a Tx PD is turned on for contention based channel request to the time that the Tx PD is successfully discovered by the **first** Rx PD.
- Power consumption
  - "to discover" power consumption (measured in scenario 1):
    - This metric is determined as the total power consumed by a Rx PD for listening to the channel and receiving either the beacon or discovery request message to discover a Tx PD.
  - 'to be discovered' power consumption (measured in scenario 2):
    - This metric is determined as the total power consumed by a Tx PD from the time of requesting the channel to the time when all Rx PDs have discovered the Tx PD.

Discovery Performance Metrics (Cont.)

- Rx PD discover ratio:
  - This metric is determined as the ratio between the number of Rx PDs that successfully discover the desired Tx PD and the total number of Rx PDs

"to discover" Latency *vs* Ratio (Scenario 1)

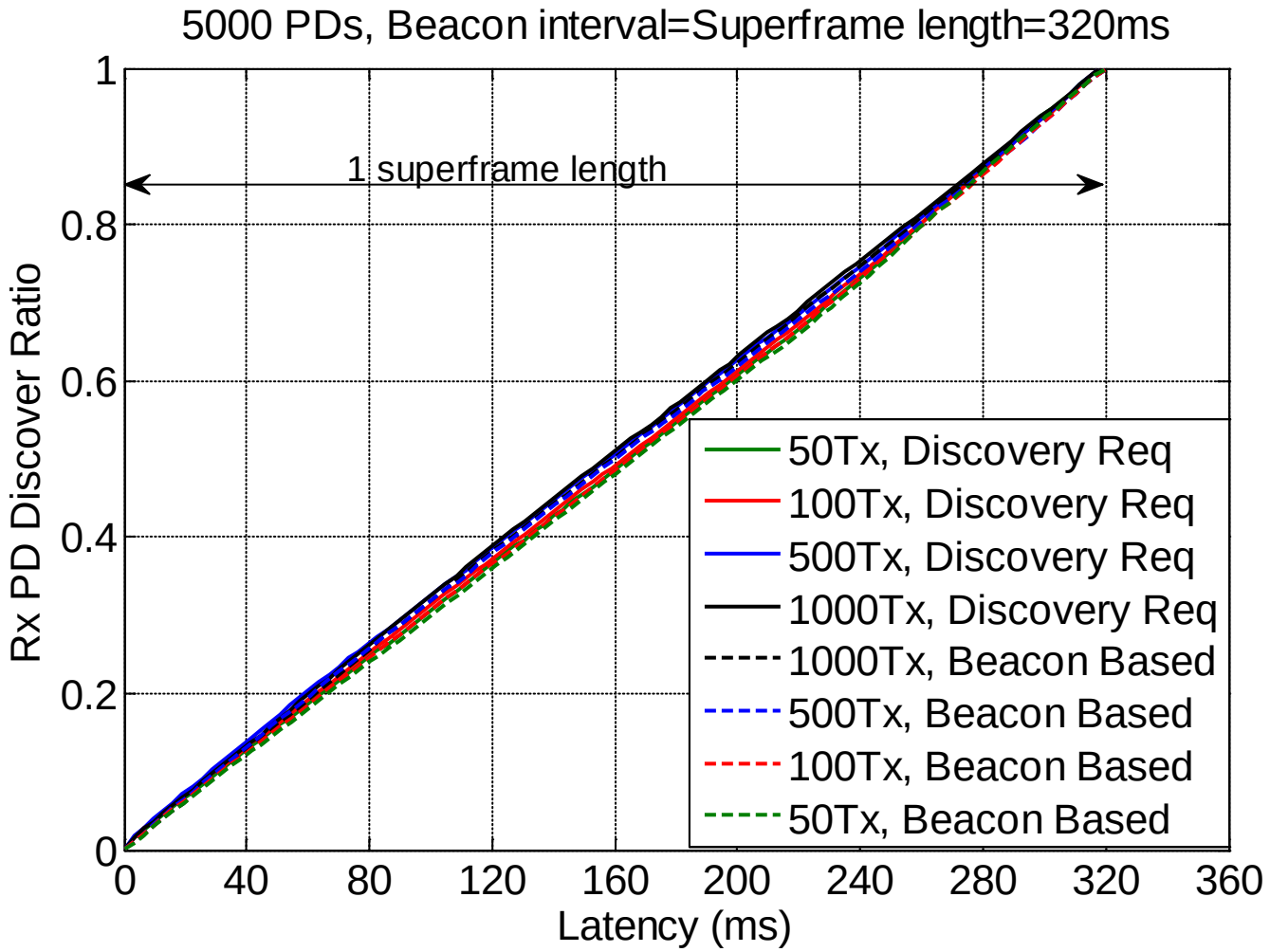


Discovery Request scheme achieves a shorter latency than the Beacon Based scheme due to:

1) Rx PD is randomly turned on
2) Repeated discovery requests offers more chances for discovery in the Discovery Request scheme

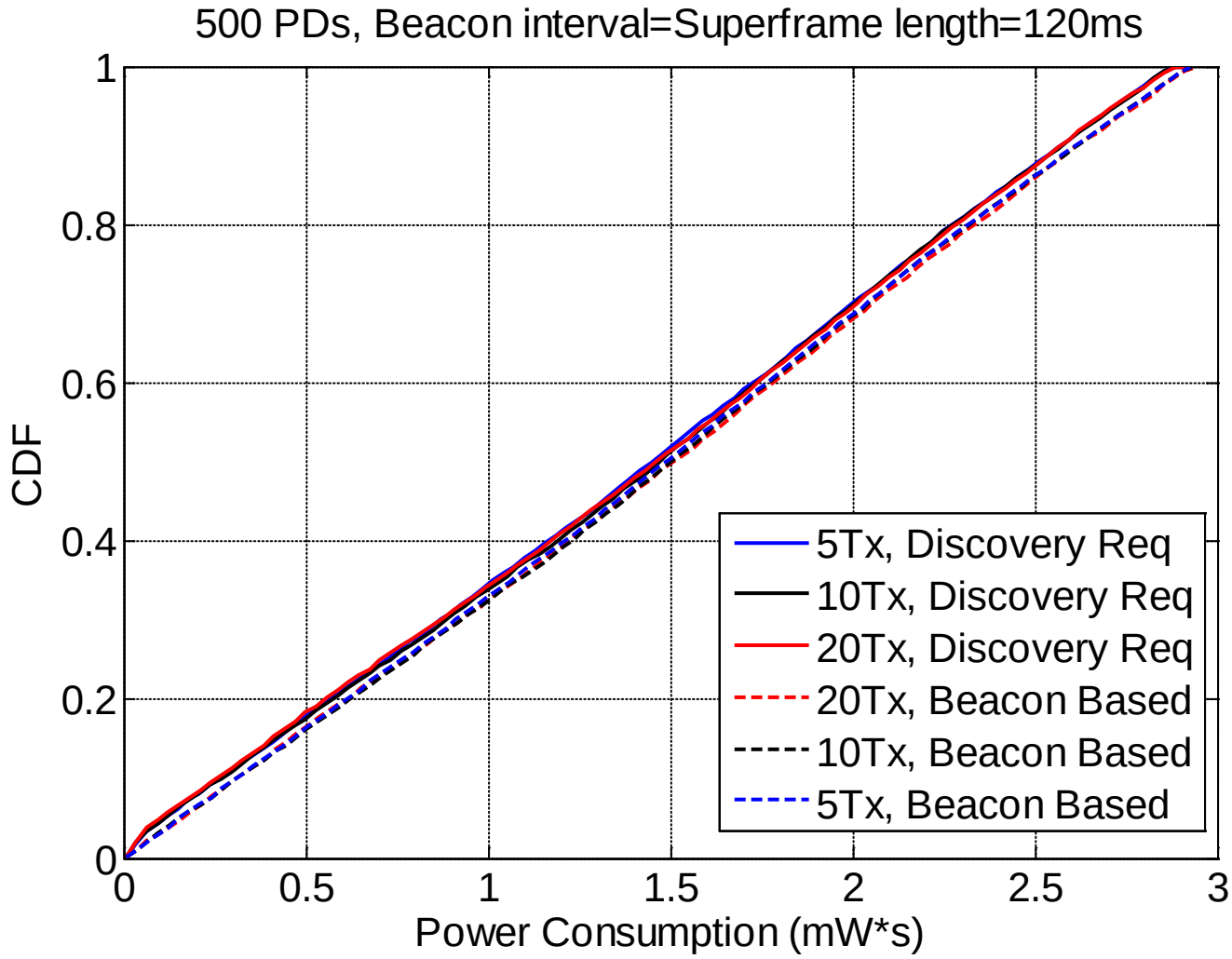
All Rx PDs discover the desired Tx PDs within 1 superframe after turned on

" to discover" Latency *vs* Ratio (Scenario 1)

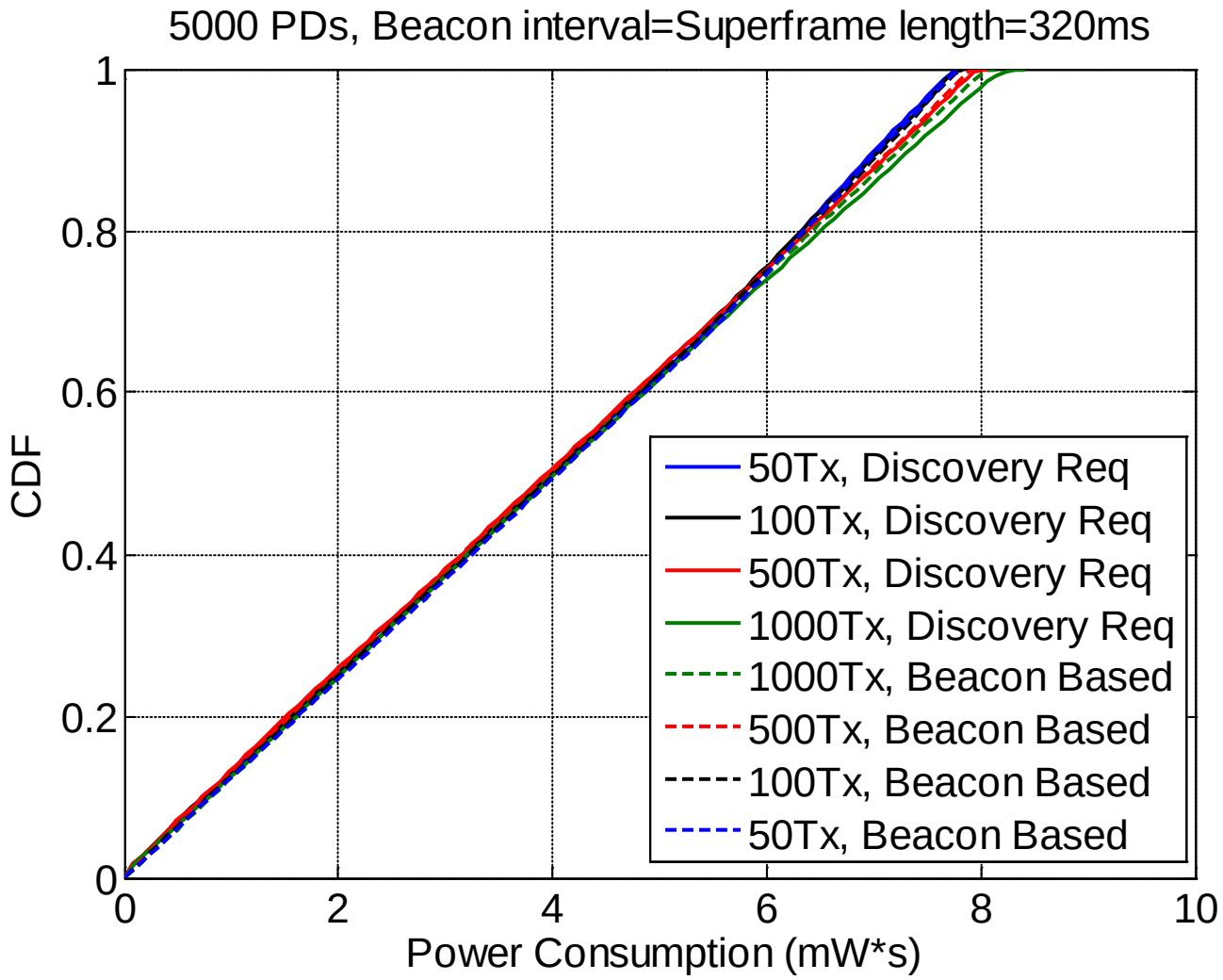


All Rx PD discovers the desired Tx PD within 1 superframe after turned on

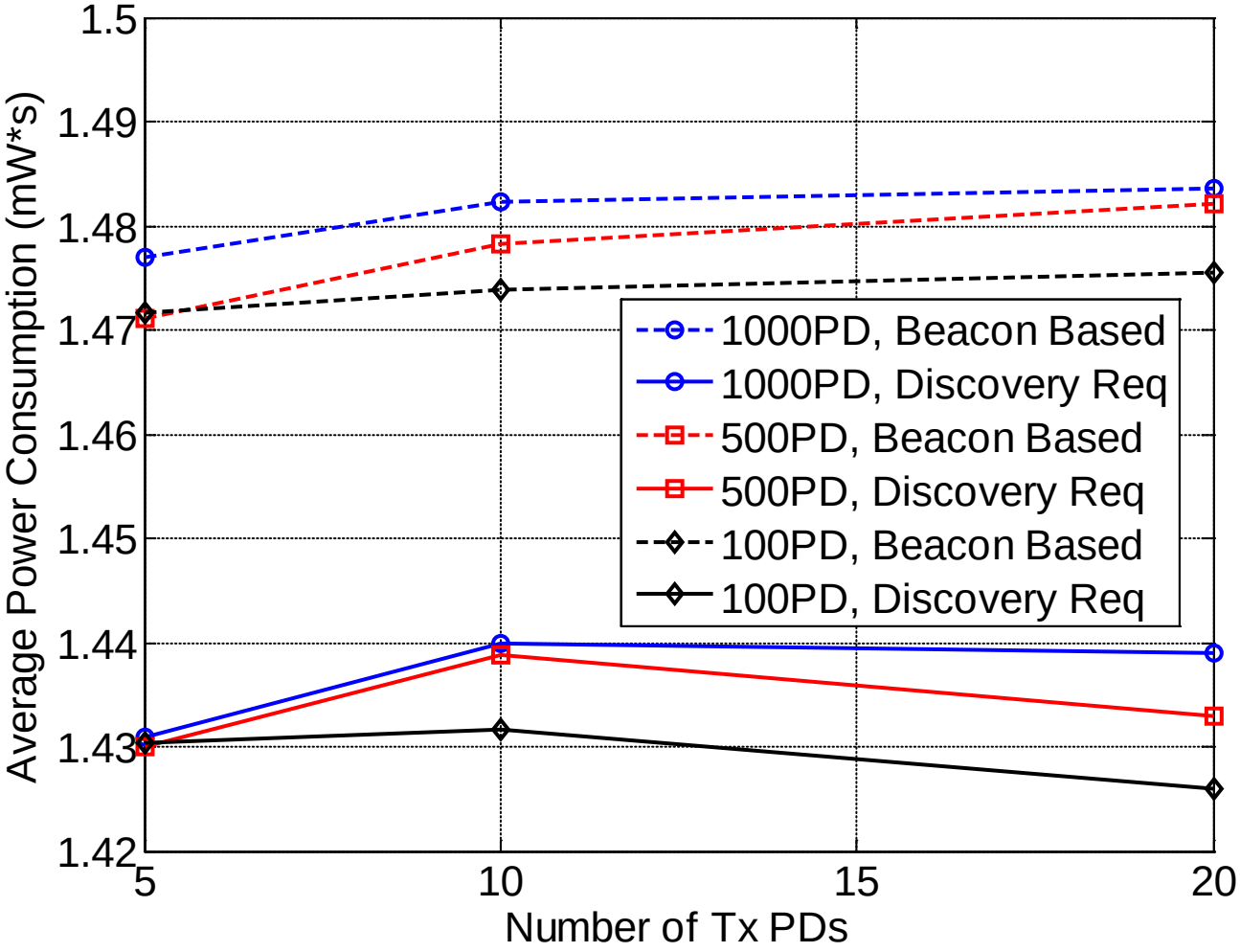
CDF of “to discover” Power Consumption (scenario 1)



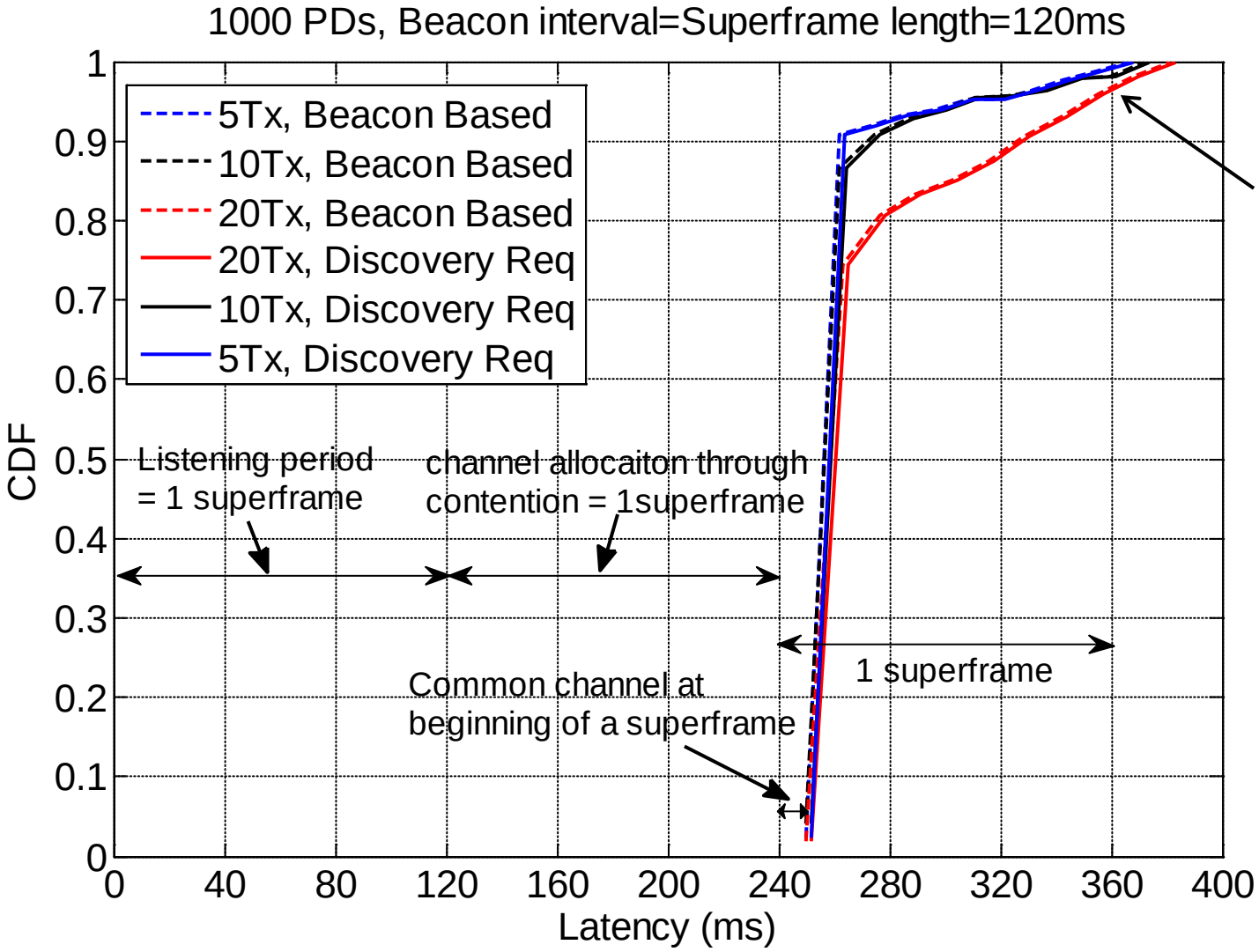
CDF of “to discover” Power Consumption (Scenario 1)



Number of Tx PDs *vs* Average "to discover" Power Consumption (Scenario 1)



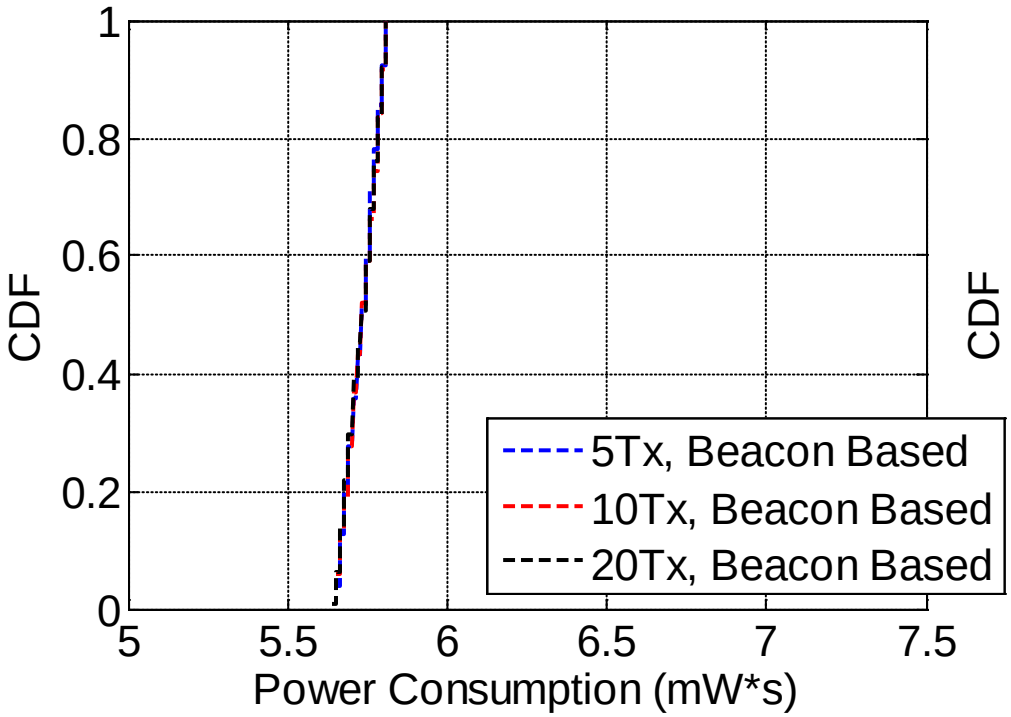
CDF of " to be discovered" Latency (Scenario 2)

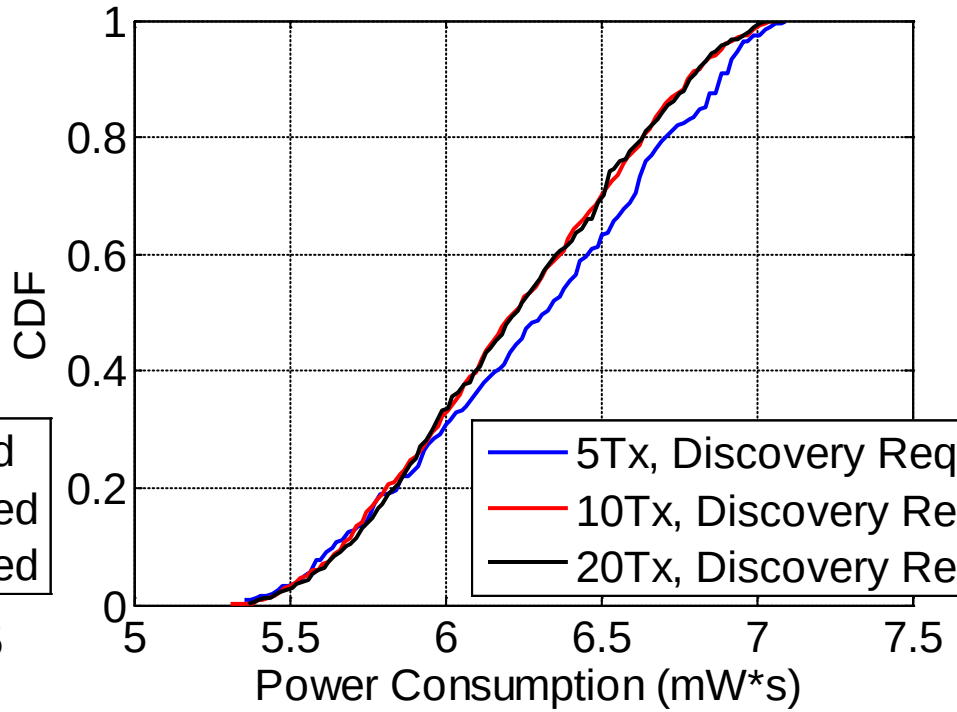


Over 95% of Tx PD are discovered by all its Rx PDs within 3 Superframes from the starting time.

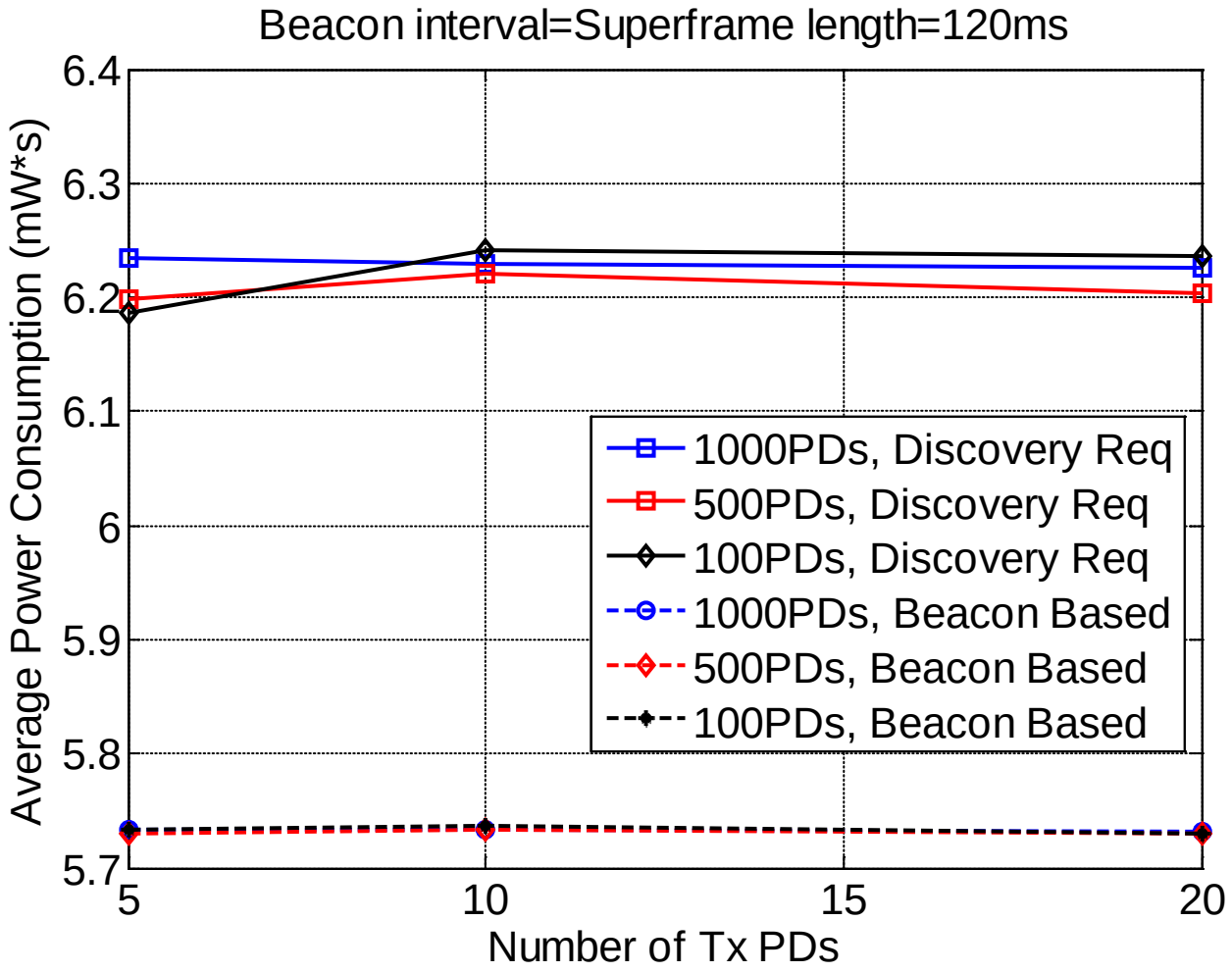
CDF of “to be discovered” Power Consumption (Scenario 2)

1000 PDs, Beacon interval=Superframe length=120ms





Number of Tx PDs *vs* Average "to be discovered" Power Consumption (scenario 2)



Conclusion--Discovery

- Discovery Latency
  - The ‘to discover’ latency will not exceed 1 Superframe length for all Rx PDs, which is independent of network density.
  - The ‘to be discovered’ latency will not exceed 4 Superframes for all Tx PDs, which is independent of network density.
  - Discovery Request scheme has a shorter latency than Beacon Based scheme.
- Power Consumption
  - Beacon Based scheme consumes similar amount of power as Discovery Request scheme.
- Rx PD discover ratio
  - All Rx PDs are able to discover the desired Tx PD within 1 Superframe, i.e., the discovery ratio is 100%.

2. Performance of Peering/Association Procedure

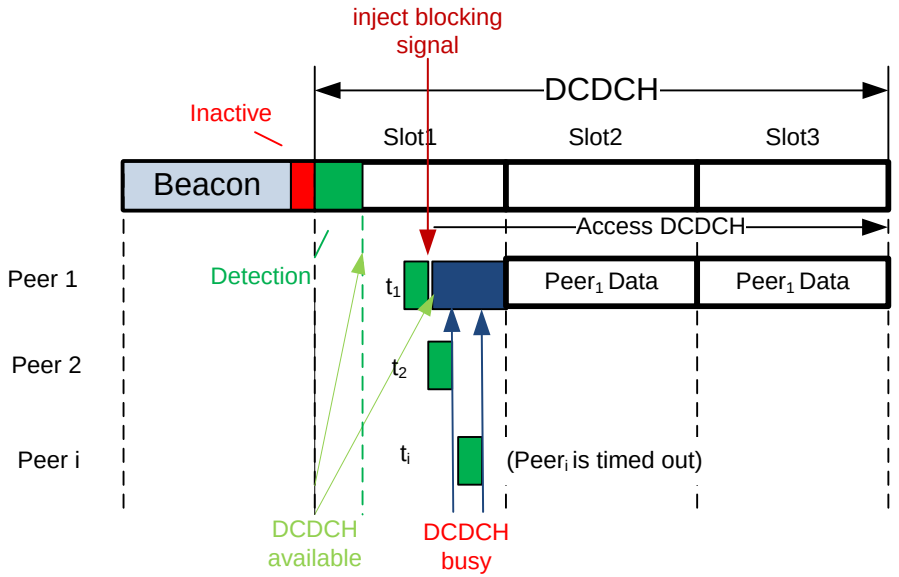
Terms and Concepts

- Peering Requestor
  - The PD that initiates the peering (association) process by sending a peering (association) request message to the Peering Responder.
- Peering Responder
  - The PD that receives the peering (association) request message and sends a peering (association) response message to the Peering Requestor.
- CAP (Contention Access Period)
  - First part of an application frame after application beacon, i.e., DCDCH.
- CFP (Contention Free Period)
  - Second part of an application frame after CAP.

Background--Peering (Association)

- Peering Schemes
  - CAP/CFP-based
    - Peering Requestors send peering request messages during CAP.
    - Peering Responder sends response messages during CFP.
      - Unicast separate responses to each peering requestor.
      - Broadcast an aggregated response to all peering requestors.
  - CAP-based
    - Peering Requestors send peering request messages during CAP.
    - Peering Responder sends response messages during CAP
      - Unicast separate responses to each peering requestor.
      - Broadcast an aggregated response to all peering requestors.
- Channel Access Schemes
  - Fast Channel Access (FCA):
    - A PD contends channel with a priority randomly chosen from [1, #Priority Classes]
    - A PD performs backoff for a period randomly chosen from [1,t_{DCDCH}] when it senses channel busy or experiences a transmission failure.
  - Slotted CSMA/CA
- Initial Backoff (IBF)
  - PDs perform an initial backoff before contending for the channel.

Fast Channel Access (FCA)

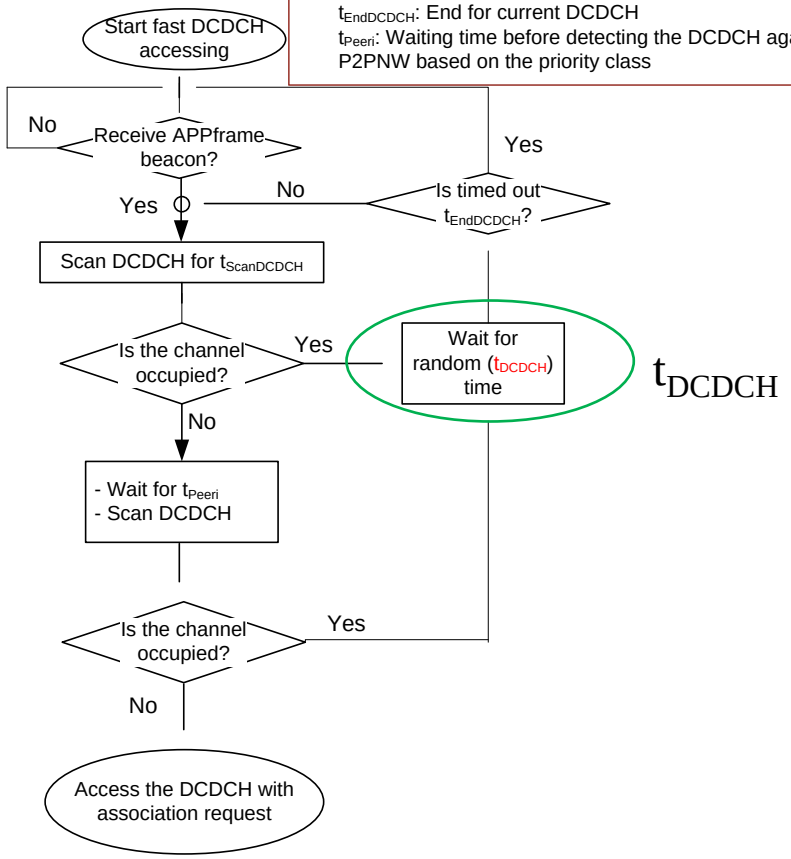


Priority-based DCDCH Access

Notes

Parameters

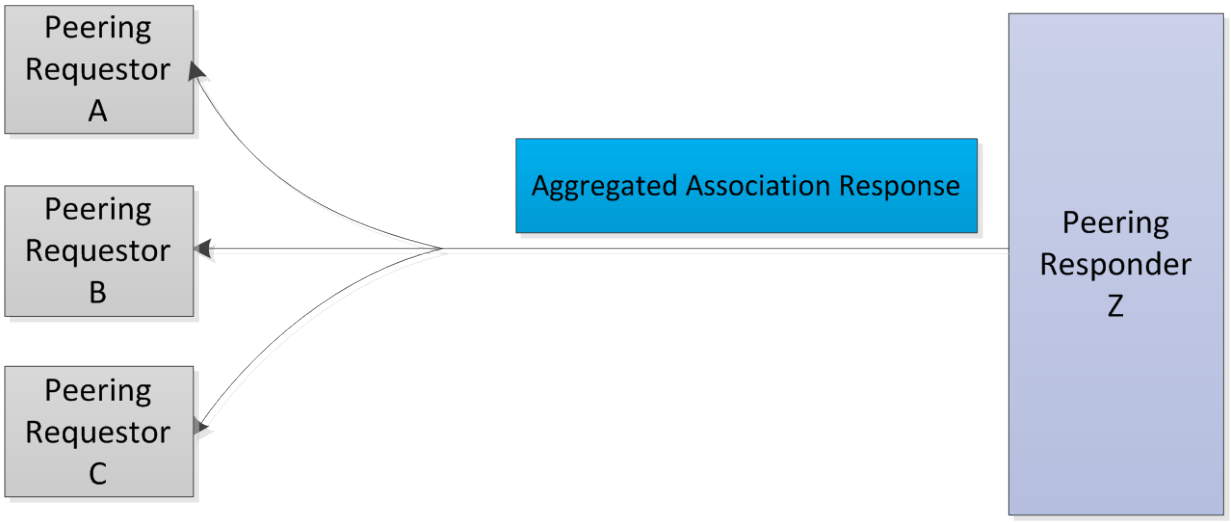
- $t_{ScanDCDCH}$: time window for scanning DCDCH
- t_{DCDCHi}: initial waiting time before peer i detects the DCDCH again
- $t_{EndDCDCH}$: End for current DCDCH
- t_{Peeri}: Waiting time before detecting the DCDCH again by Peer i of P2PNW based on the priority class



Fast Channel Access for Intra-P2PNW Communications through DCDCH

Aggregated Peering (Association) Response

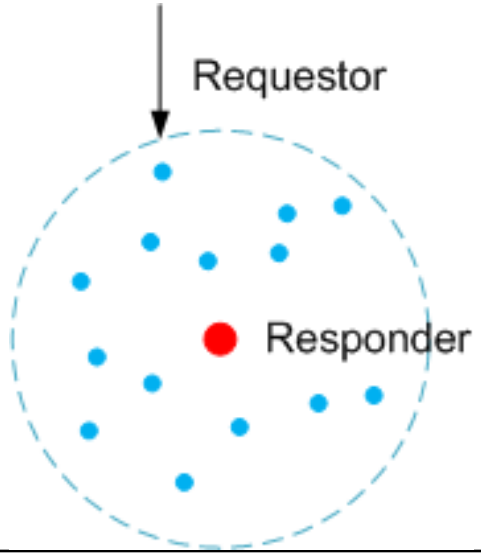
After received peering (association) request messages from PD A, B and C, responder Peer Z will broadcast a single aggregated peering (association) response message to three PD A, B and C.



Simulation Configuration

- Network Configuration
  - There are 100 PDs in the network (i.e. 99 Peering Requestors and 1 Peering Responder)
  - Peering Requestors are randomly placed within 50 meters from the Peering Responder.
  - All Peering Requestors start peering process at time 0.
  - The transmission of each peering request or response message can be completed within 1 slot (i.e. 1 ms).
- Simulation Scenarios
  - Set 1: CAP/CFP-based Peering, FCA priority range [1, 10], slotted CSMA/CA, IBF enabled or disabled.
  - Set 2: CAP/CFP-based Peering, various FCA priority range, IBF disabled.
  - Set 3: CAP/CFP-based & CAP-based Peering, FCA priority range [1, 10], slotted CSMA/CA, IBF disabled.

Parameter	Value
Slot size	1 ms
DCDCH (CAP) length	9 ms (9 slots)
CFP length	1 ms (1 slots)
Application frame length	10 ms (10 slots)
Superframe length	100 ms (100 slots)
General parameters	TGD revision 7 [1]



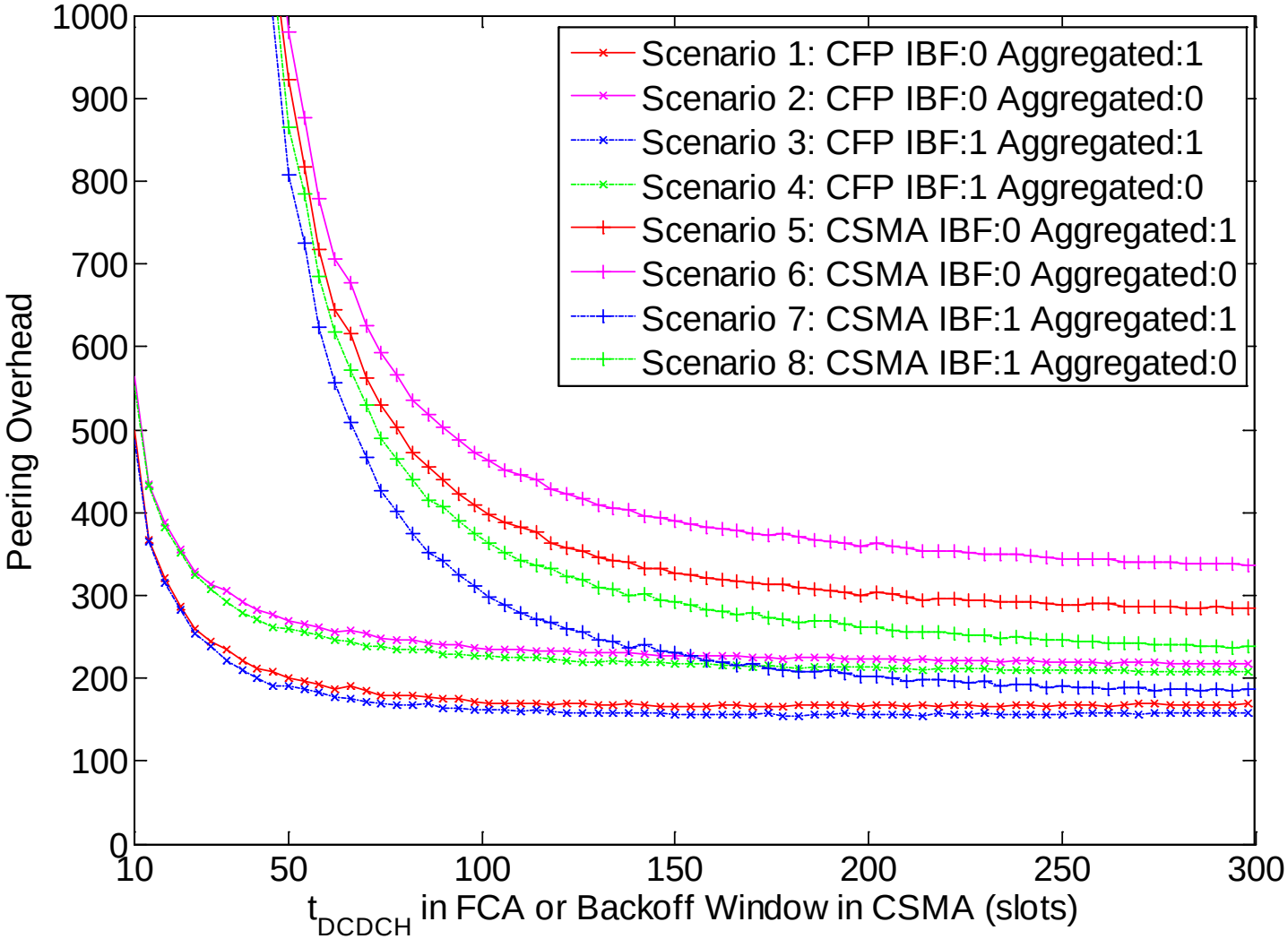
Performance Metrics--Peering (Association)

- Peering overhead: total number of messages (request and response) transmitted by all PDs until all Requestors are peered.
- Peering latency: the time (in Superframes) from all the Requestors start the peering procedure to the time that all Requestors are peered.

Simulation Scenario--Set 1

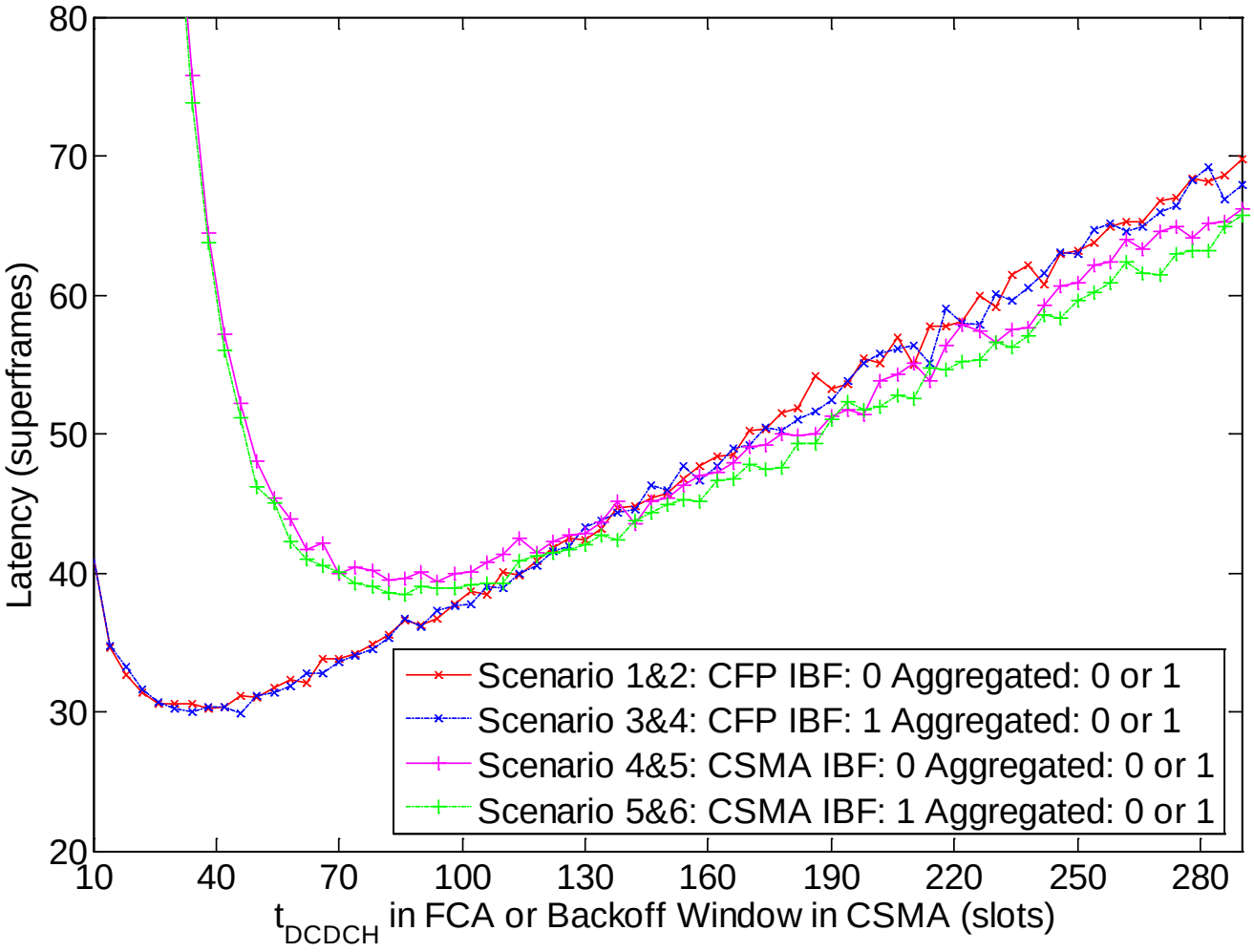
Scenario	Request message on	Response message on	Channel Access	Priority Range	IBF	Aggregated Response
1	CAP	CFP	FCA	[1,10]	N	Y
2	CAP	CFP	FCA	[1,10]	N	N
3	CAP	CFP	FCA	[1,10]	Y	Y
4	CAP	CFP	FCA	[1,10]	Y	N
5	CAP	CFP	CSMA	N/A	N	Y
6	CAP	CFP	CSMA	N/A	N	N
7	CAP	CFP	CSMA	N/A	Y	Y
8	CAP	CFP	CSMA	N/A	Y	N

Simulation Results--Peering Overhead



- Scenario 3 achieves the best performance (i.e. FCA with Initial Backoff and aggregated response)
- The use of aggregated scheme reduces peering overhead.
- FCA performs better than CSMA.
- IBF reduces less overhead for FCA compared with CSMA.

Simulation Results--Peering Latency

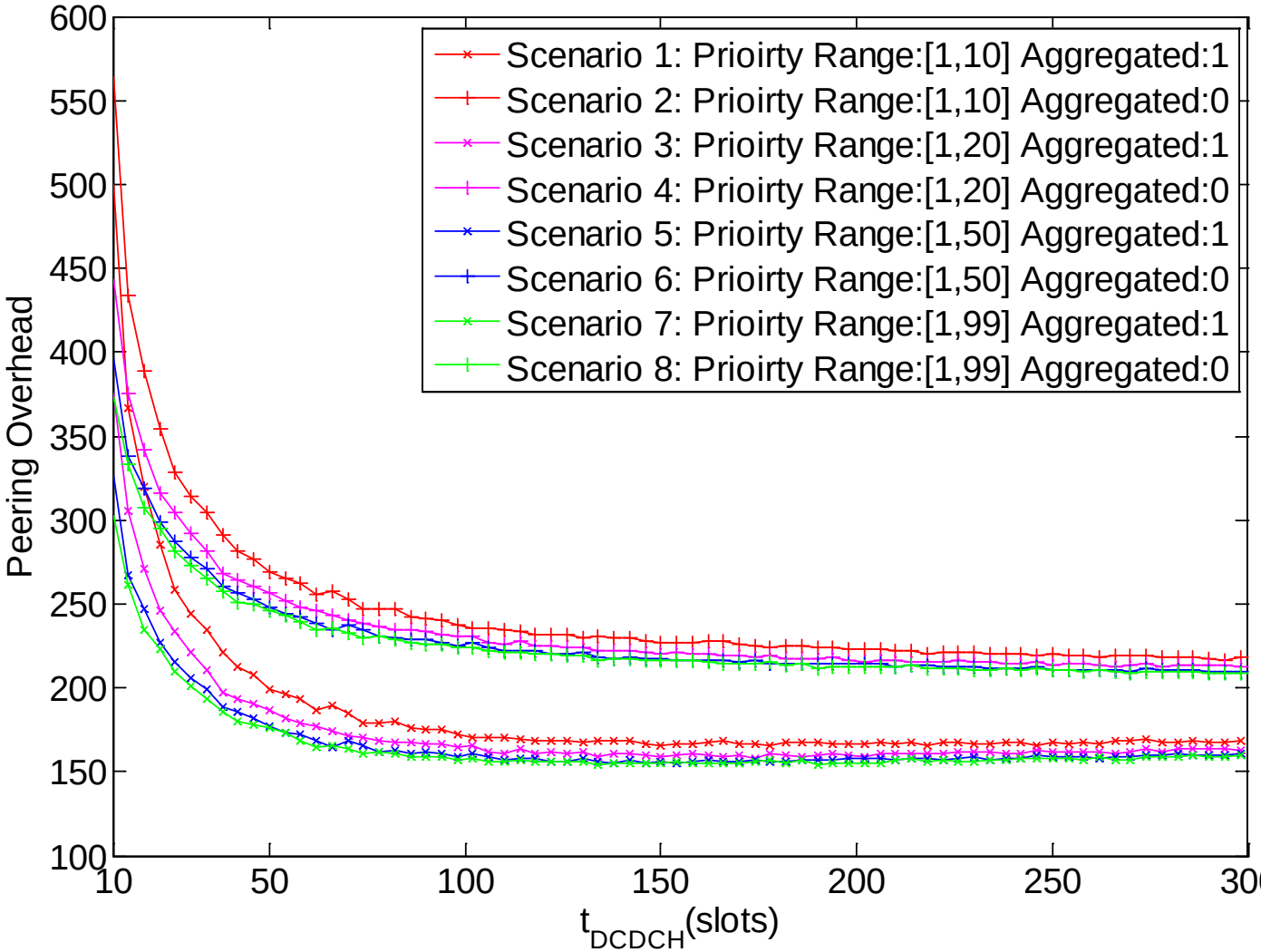


- FCA performs better than slotted CSMA/CA.
- IBF decreases the latency for slotted CSMA/CA, but has little impact on FCA.

Simulation Scenario—Set 2

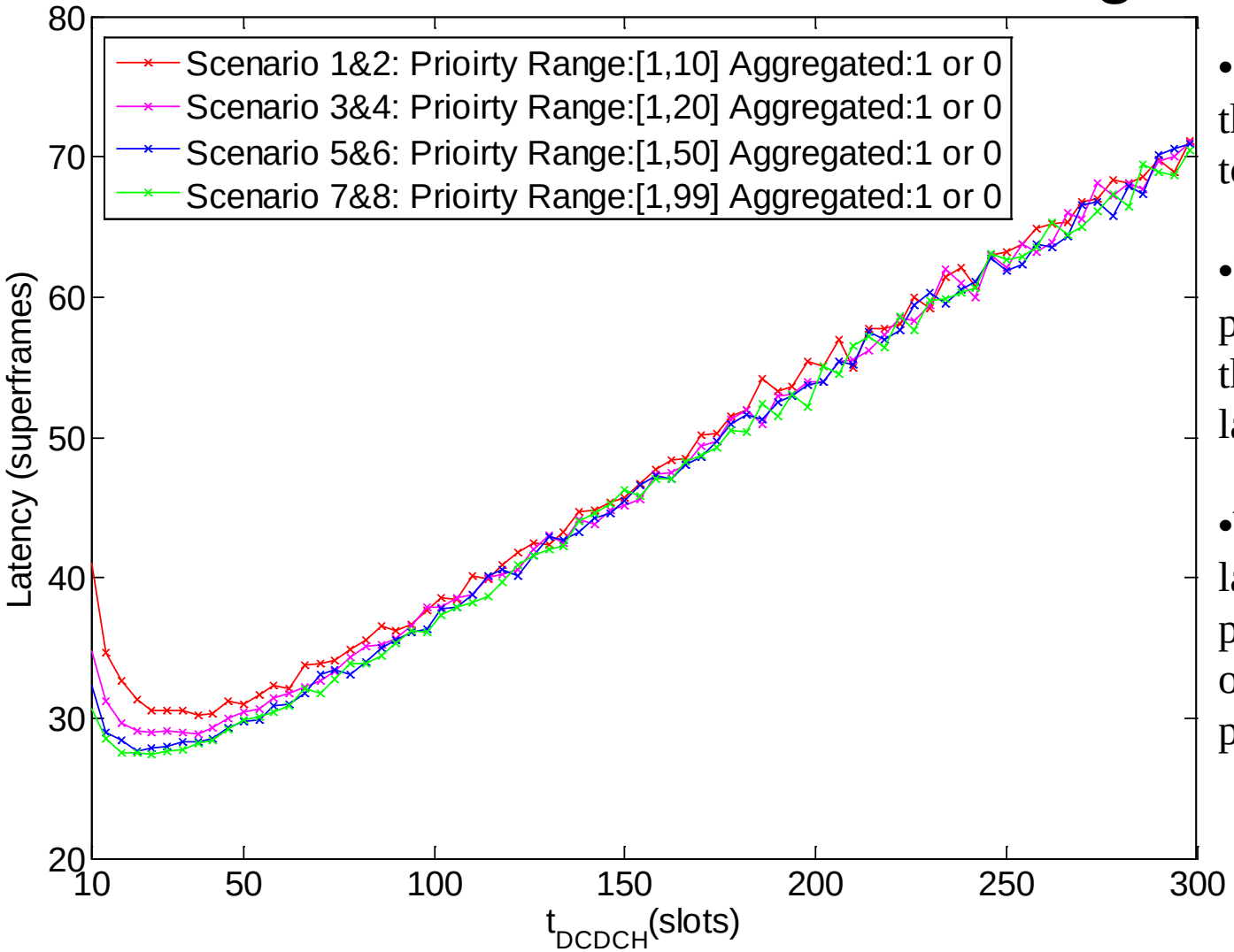
Scenario	Request message on	Response message on	Channel Access	Priority Range	IBF	Aggregated Response
1	CAP	CFP	FCA	[1,10]	N	Y
2	CAP	CFP	FCA	[1,10]	N	N
3	CAP	CFP	FCA	[1,20]	N	Y
4	CAP	CFP	FCA	[1,20]	N	N
5	CAP	CFP	FCA	[1,50]	N	Y
6	CAP	CFP	FCA	[1,50]	N	N
7	CAP	CFP	FCA	[1,99]	N	Y
8	CAP	CFP	FCA	[1,99]	N	N

Simulation Results--Peering Overhead



- Scenario 7 provides the best performance due to highest priority classes and aggregated response.
- The use of the aggregated scheme reduces peering overhead.
- Increasing number of priority classes reduces the peering overhead.

Simulation Results--Peering Latency

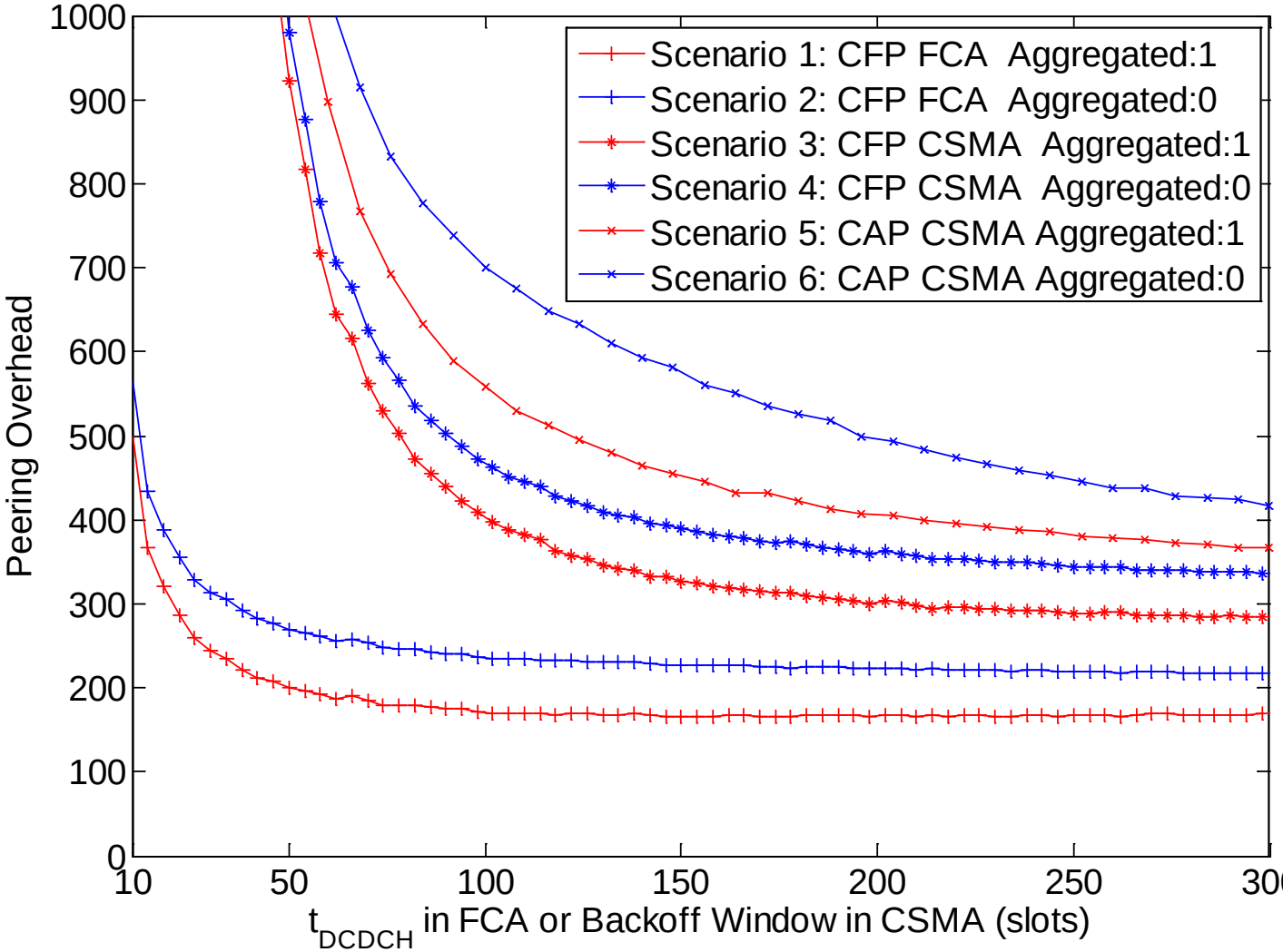


- Scenarios 7&8 achieve the best performance due to highest priority classes.
- Increasing number of priority classes reduces the minimum peering latency of FCA.
- When t_{DCDCH} becomes large, it dominates the peering latency over the other factors, such as priority class.

Simulation Scenarios--Set 3

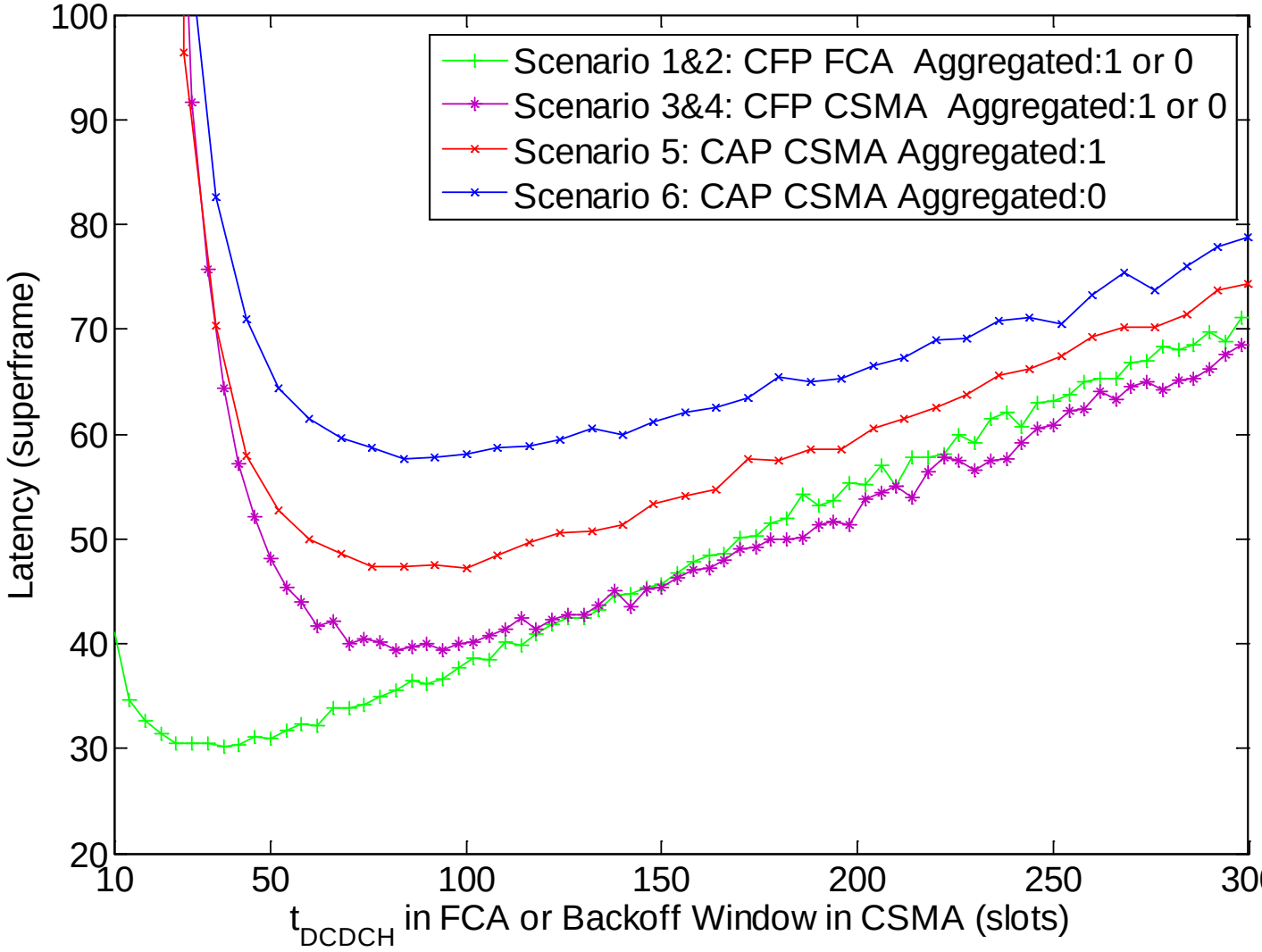
Scenario	Request message on	Response message on	Channel Access	Priority Range	IBF	Aggregated Response
1	CAP	CFP	FCA	[1,10]	N	Y
2	CAP	CFP	FCA	[1,10]	N	N
3	CAP	CFP	CSMA	N/A	N	Y
4	CAP	CFP	CSMA	N/A	N	N
5	CAP	CAP	CSMA	N/A	N	Y
6	CAP	CAP	CSMA	N/A	N	N

Simulation Results – Peering Overhead



- Scenario 5 provides the best performance (i.e. CAP/CFP based scheme with FCA and aggregated response).
- CAP/CFP-based peering scheme performs better than CAP only peering scheme.
- The use of aggregated scheme reduces the peering overhead for all schemes.

Simulation Results--Peering Latency



- Scenario 5&6 achieve the best performance (i.e. CAP/CFP-based scheme with FCA).
- CAP/CFP-based peering scheme performs better than CAP only peering scheme.
- The use of aggregated scheme reduces the peering latency for CAP-based scheme.

Conclusions

- Aggregated peering response scheme reduces the peering overhead for both slotted CSMA/CA and FCA.
- CAP/CFP-based peering scheme performs better than CAP only peering scheme.
- Fast Channel Accessing (FCA) performs better than slotted CSMA/CA.
- Initial Backoff (IBF) reduces the peering overhead more for slotted CSMA/CA than FCA.

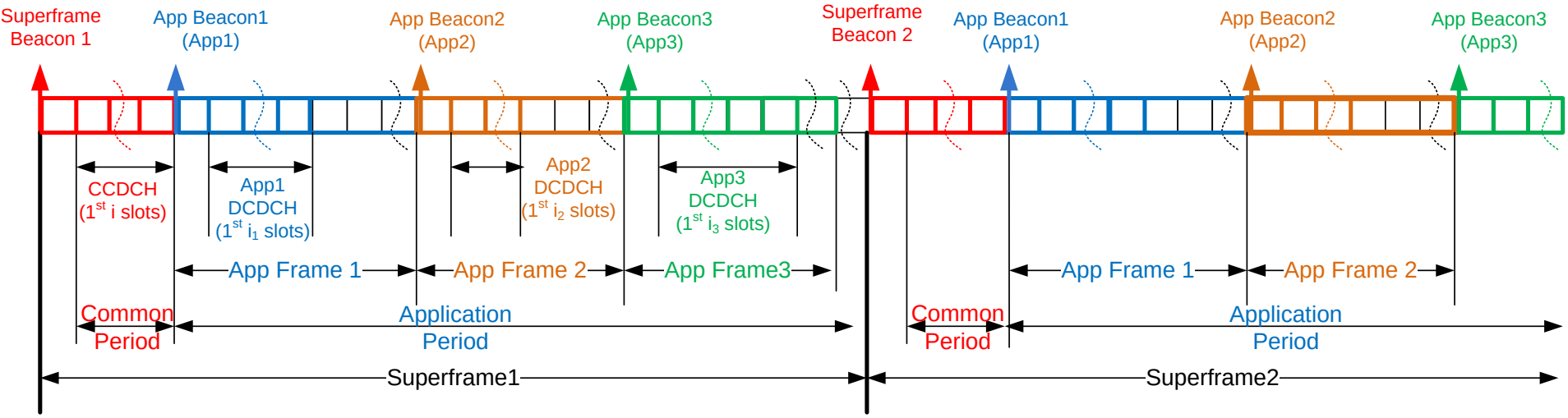
3. Performance of Data Communication

Terms and Concepts

- Tx PD: a PD that generates data packet and sends to the peered Rx PD.
- Rx PD: a PD that receives the data packet from its peered Tx PD.

Background

- Data transmission is contention free within each application frame.



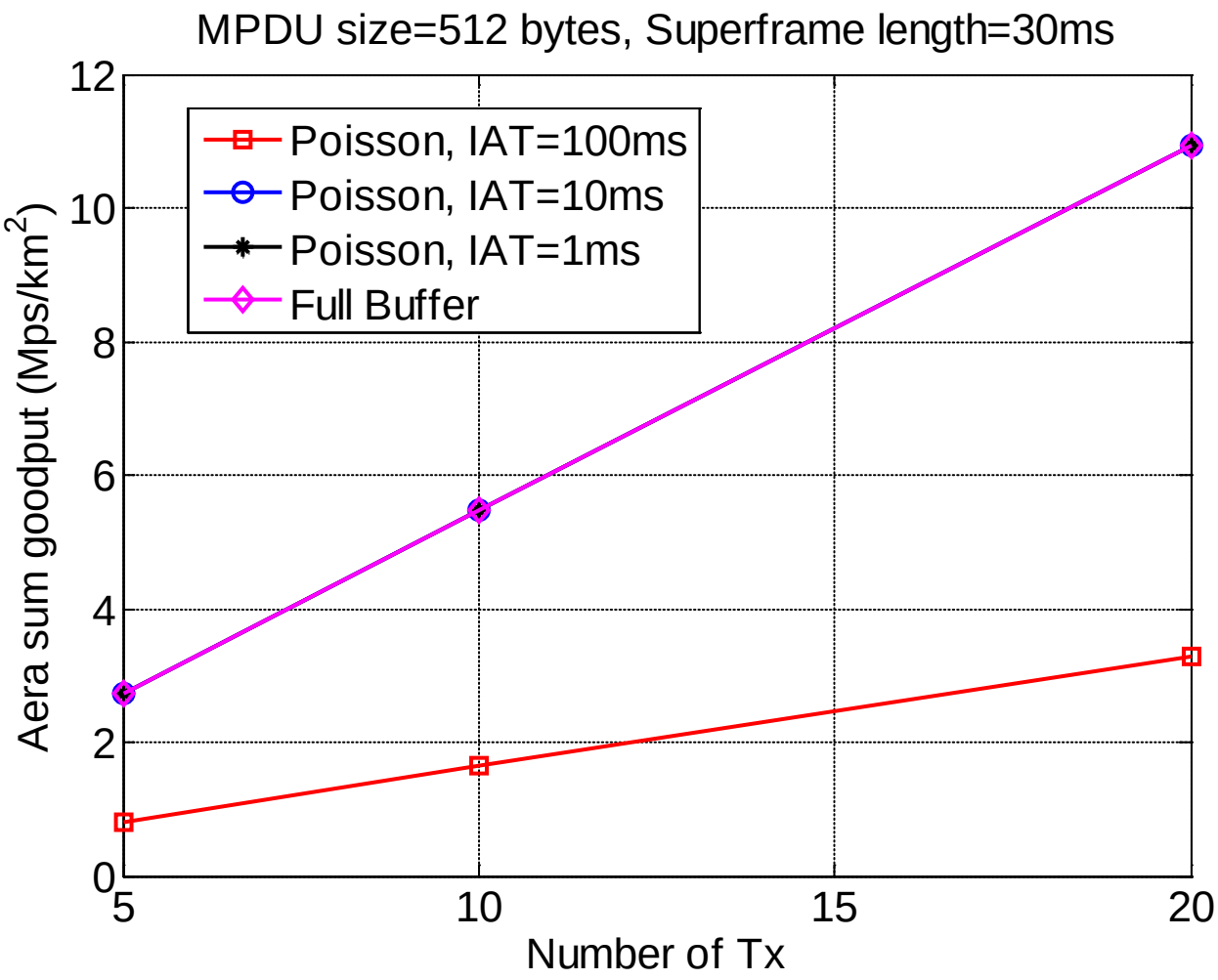
Simulation Configuration--Data Communication

Parameter	Value
Slot size	1 ms
CCDCH length	20 ms (10ms for number of Tx PD < 50)
Application frame length	1 Beacon + 1 MPDU
Number of application frames in a superframe	30 (10 for number of Tx PD < 50)
Superframe length	(Number of application frames in a superframe * Application frame length) + CCDCH length
Beacon interval	1 superframe length
Bandwidth	10 MHz
Channel data rate	9 Mbps (QPSK, 3/4)
General parameters	TGD revision 7 [1]
Traffic model	Full buffer & Poisson arrival

Performance Metrics

- Area sum goodput: Mbps/km^2
- Jain's fairness index
- MAC-to-MAC latency (only for Poisson arrival)
  - From the time instant that the MAC at Tx PD decides to transmit a packet to the time instant that the Rx PD successfully receives the packet at MAC.
- Data packet reception efficiency (ratio)
  - The total number of successfully received packet to the total number of transmitted packet including retransmission procedure.

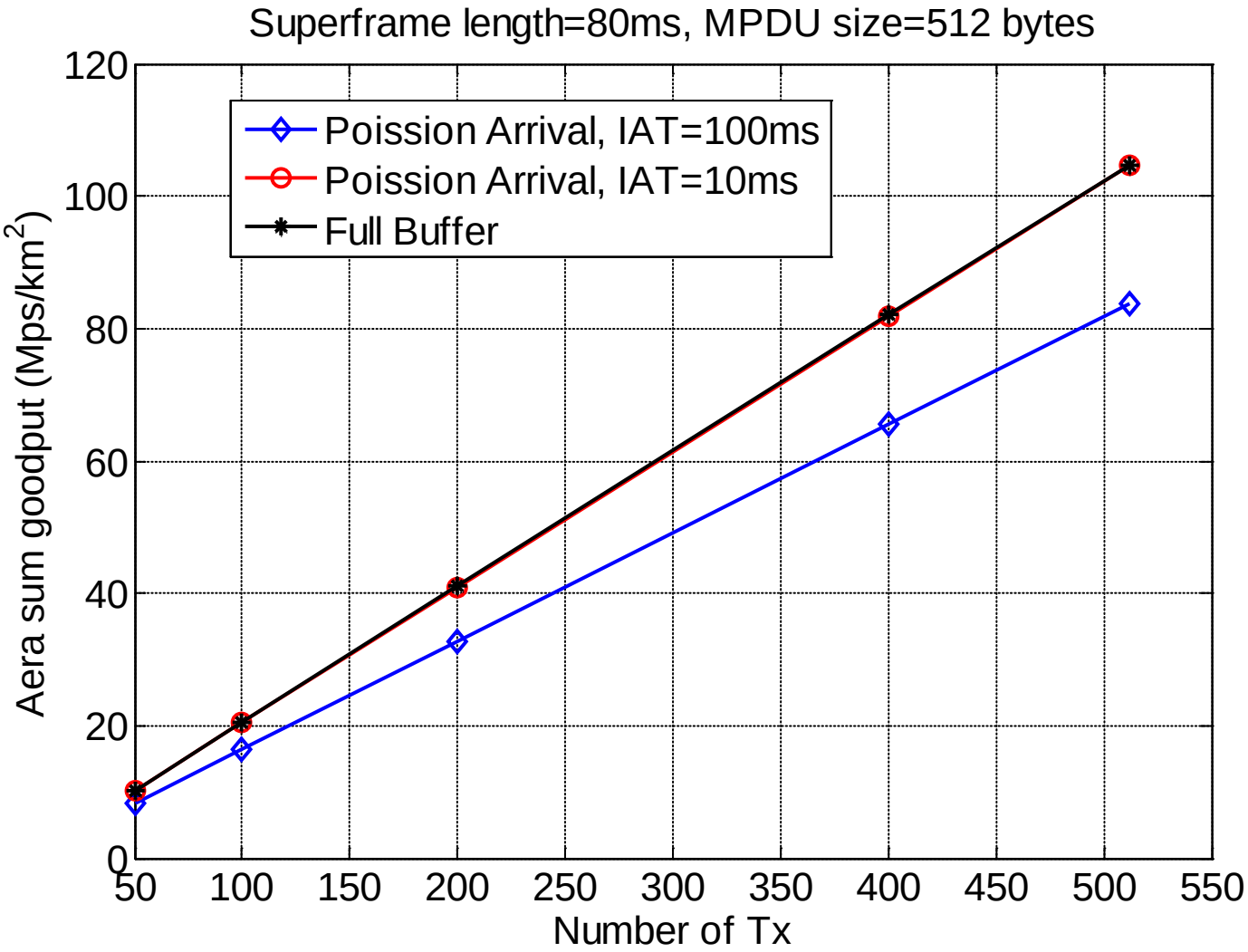
Area Sum Goodput (1)



Poisson arrival process has the same performance as the Full Buffer model on the long term, if the IAT is smaller than Superframe length.

IAT: inter-arrival time

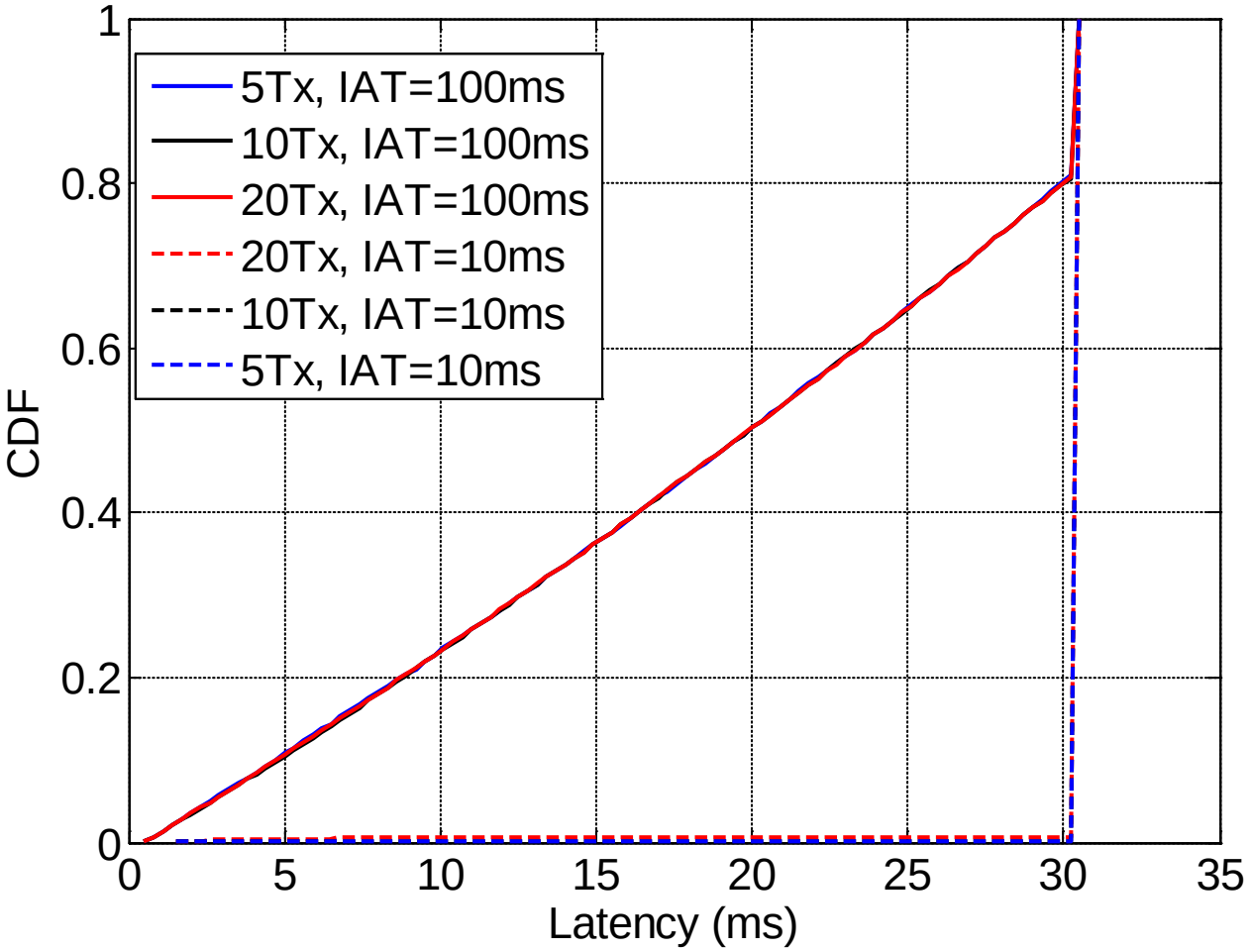
Area Sum Goodput (2)



Poisson arrival process has the same performance as the Full Buffer model on the long term, if the IAT is smaller than Superframe length.

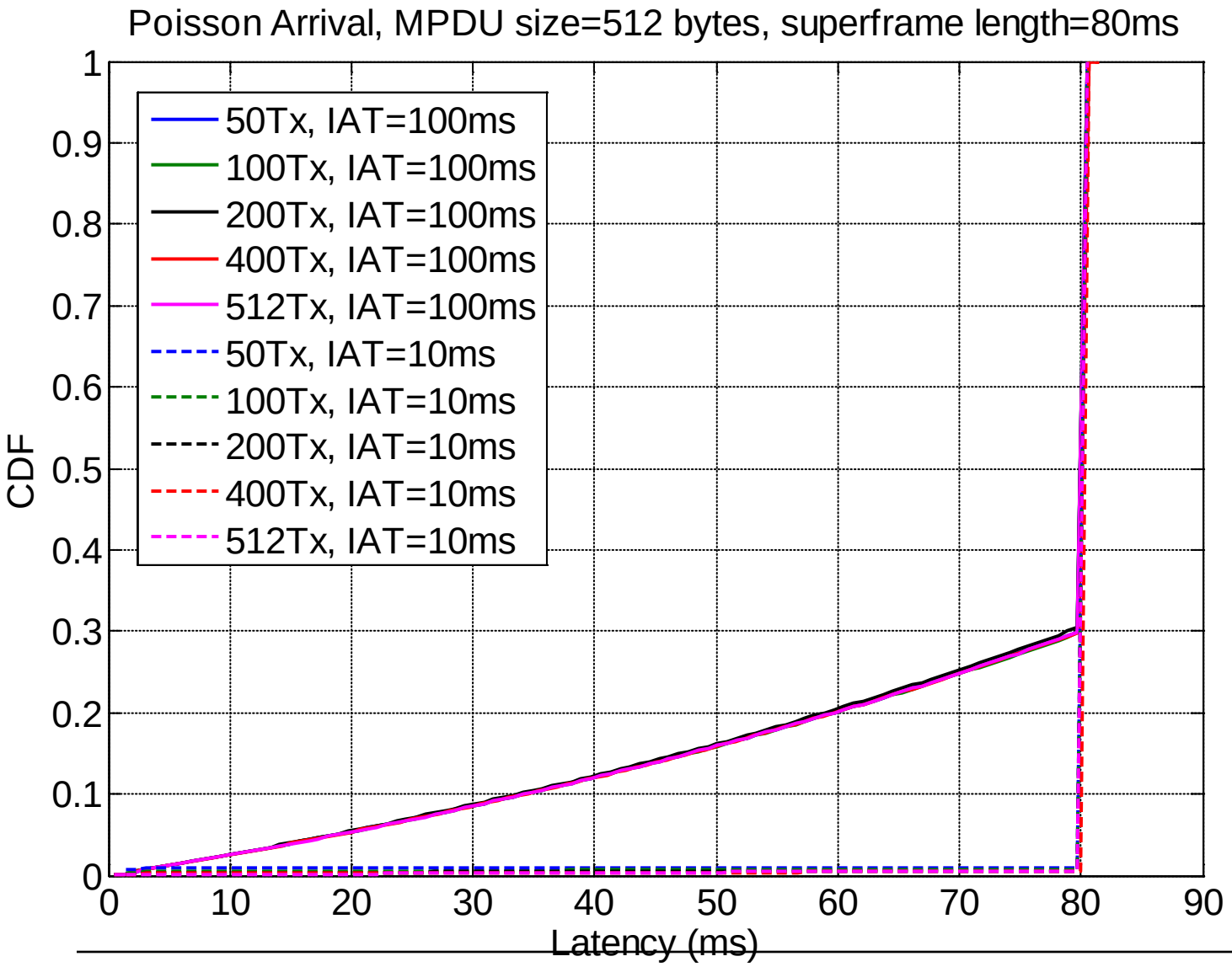
MAC-to-MAC latency (1)

Poisson arrival, MPDU size=512 bytes, superframe length=30ms



The MAC-to-MAC latency of a data packet is bounded by Superframe length.

MAC-to-MAC latency (2)



The MAC-to-MAC latency of a data packet is bounded by Superframe length.

Fairness and Efficiency

- Jain's fairness index is always close to 1 due to:
  - All Tx PDs have equal opportunity to send data within a superframe through the CFP of their application frames.
- Data packet reception efficiency (ratio) is always 1 due to:
  - Packet error rate is 0 with channel model (i.e., path loss within 50 meters) and MCS (QPSK and ¾ coding rate).
  - Data is transmitted over CFP within each application frame.

Conclusion

- MAC-to-MAC latency is bounded by the Superframe length due to the contention free data transmission.
- Each Tx PD achieves almost the same throughput (i.e., the fairness index is close to 1).

References

- [1] IEEE 802.15.8 Technical Guidance Document
- [2] Interdigital's final proposal: IEEE-15-13-0380-02-0008

Thank You!

Any Questions?

➔ Qing.Li@InterDigital.com