Impact of MAC Protocol on Wireless Distributed Computing Applications

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Agenda

- Targets / Questions
- Selection of Cases for Analysis
  - Media Access Control Protocols
  - Topologies
  - Frequency Planning / Duplexing / Gender
  - Capacity Calculation
- Selecting Comparison Criteria
  - Load Factor Crossover Point
- Analysis
- Conclusions

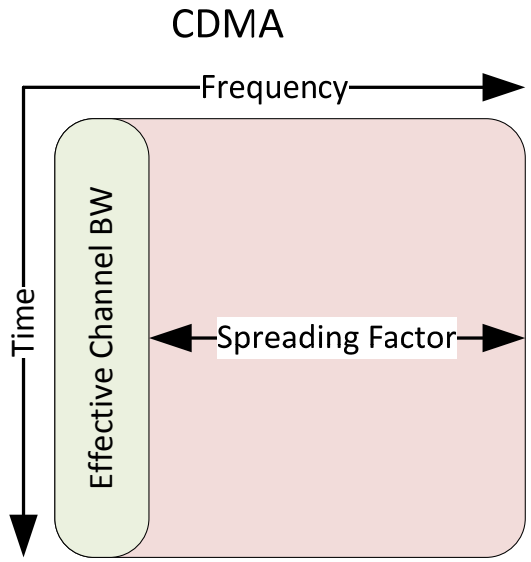
Targets / Questions

- Every MAC Protocol has its own sources of inefficiencies
  - Are there any that are clearly better for Wireless Distributed Computing applications?
  - Are there circumstances where one is clearly better?
- How do I select the definition of “Better”
  - Is there something about WDC Applications that can be exploited?

Selection of Cases

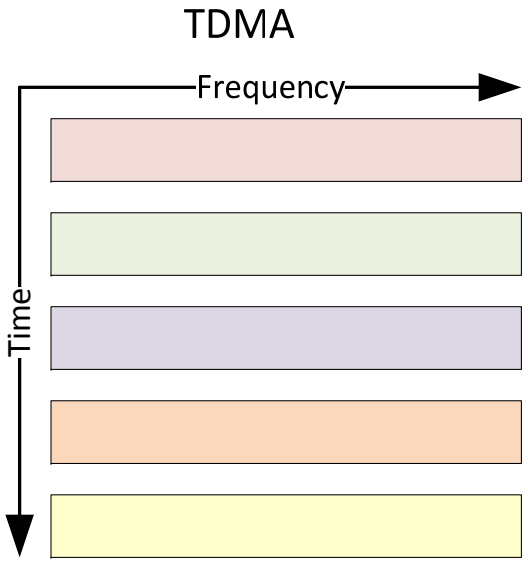
- Select MAC Protocols
  - What are sources of Inefficiencies / losses?
    - Scheduling
    - Resource Allocation
- Case Validity
  - Too many cases to cover, so, we decided to deliberately generate contrasts
    - Somewhat artificial but still valid for the question of how to tell if one is better than another
- Cases Selected
  - MAC Protocols: CDMA / FDMA / TDMA / CSMA
  - Spatial Conditions: Round Robin / Hub/Spoke

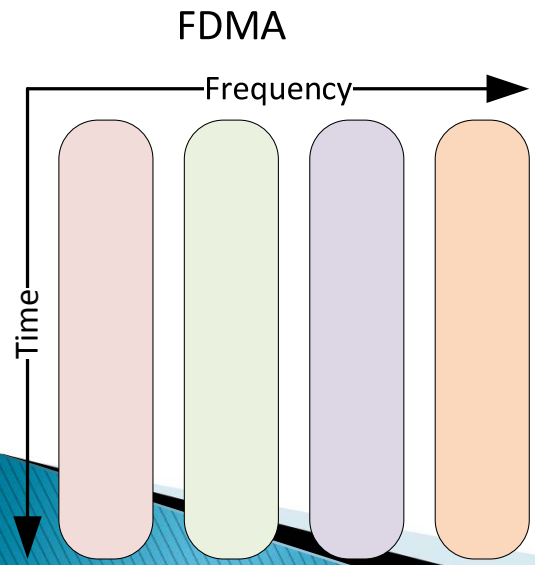
MAC Protocols Selected



CDMA Losses:
Frequency to
Coding/Hopping

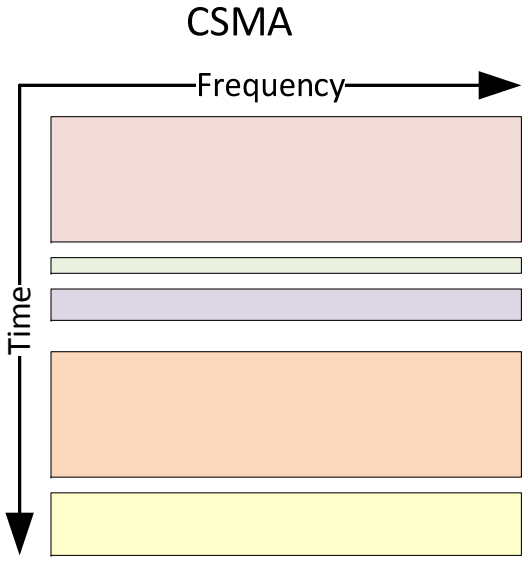
TDMA Losses:
Slot Guard Time





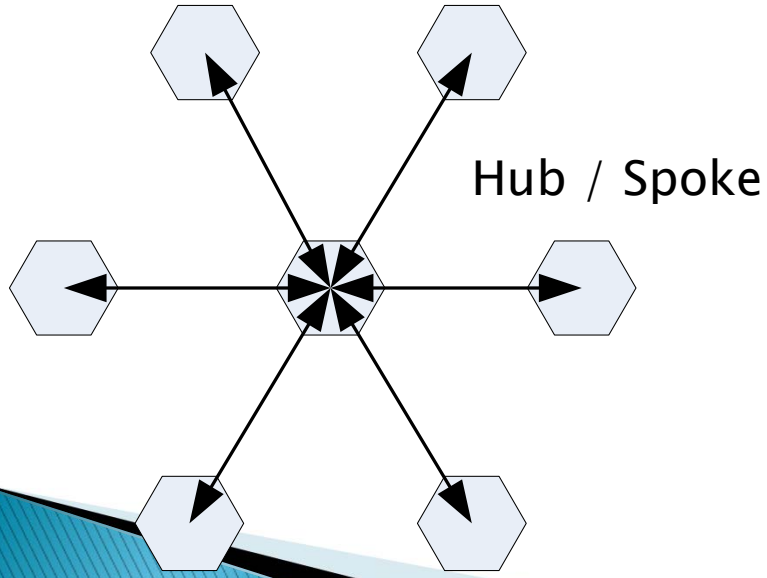
FDMA Losses:
Frequency to
Guard Bands

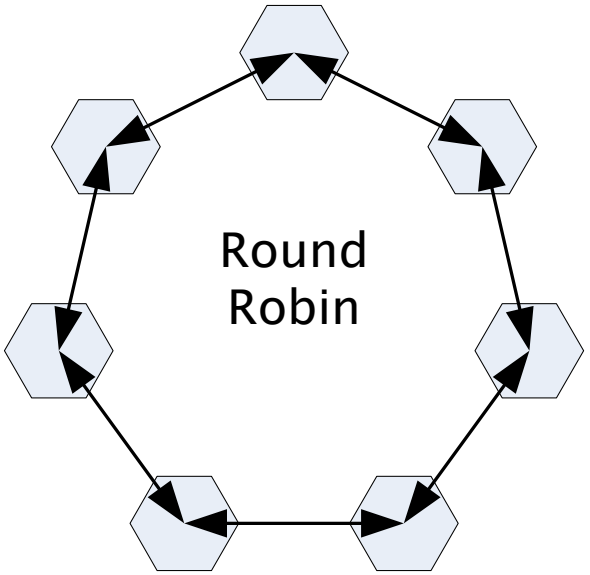
CSMA Losses:
Packet Guard Time



Spatial Conditions Selected

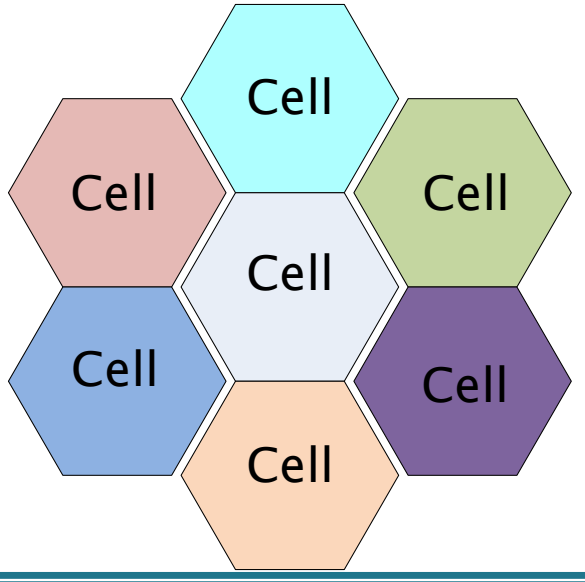
- Hub / Spoke
  - 100 m Diameter
  - Pedestrian Speeds
  - Omni-directional Antennas
- Round Robin
  - 500 km Diameter
  - Satellite Speeds
  - Highly Directional Antennas





Generating Contrasts – CDMA

- CDMA vs Others
  - CDMA not affected by Cell frequency planning
  - All other MAC Protocols must ensure that adjacent cells have a different frequency allocation (color) in larger deployments
  - CDMA is affected by Processing Load factor



So: We chose to include Frequency Planning Constraints

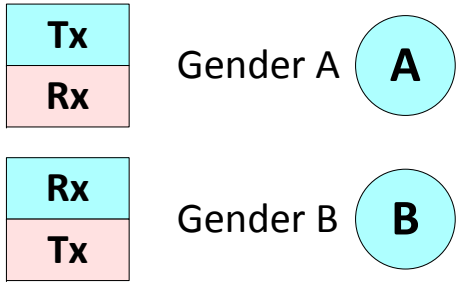
So: We included multiple Processing Gain factors

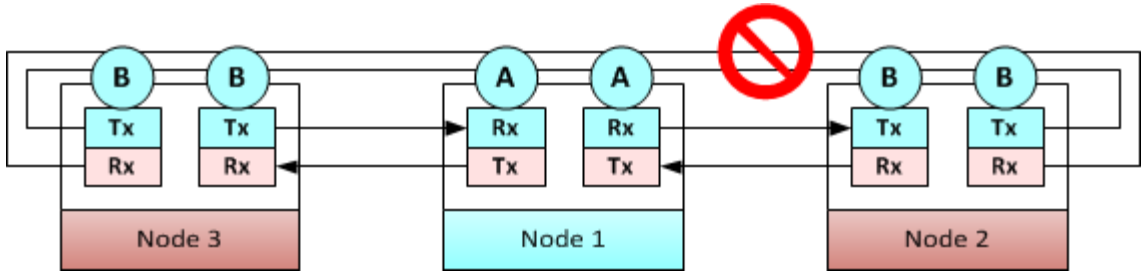
Generating Contrasts – Duplexing

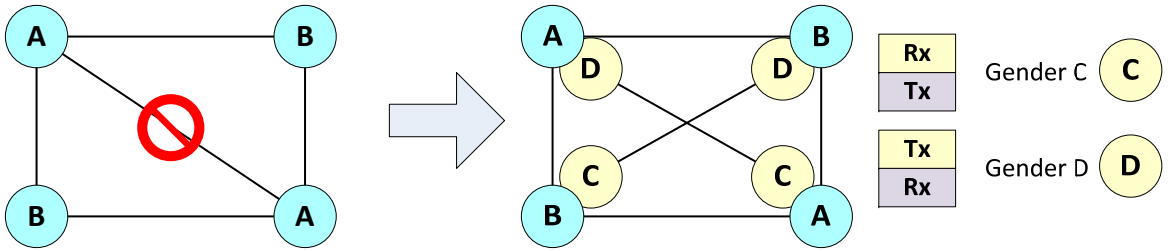
- Channel Separation for Transmit vs Receive on same terminal
  - Approaches: Time / Frequency / Physical separation
  - Min Separation often tens of meters – so for most platforms ➔Time or Frequency Duplexing
- Frequency Duplexing Contrast:
  - Can't mix Transmit & Receive Frequencies on same node
- So: A selection of cases includes both Time & Frequency Duplexing

Case Selection Issues: Gender

- Call pairing of Tx & Rx Frequencies a Gender



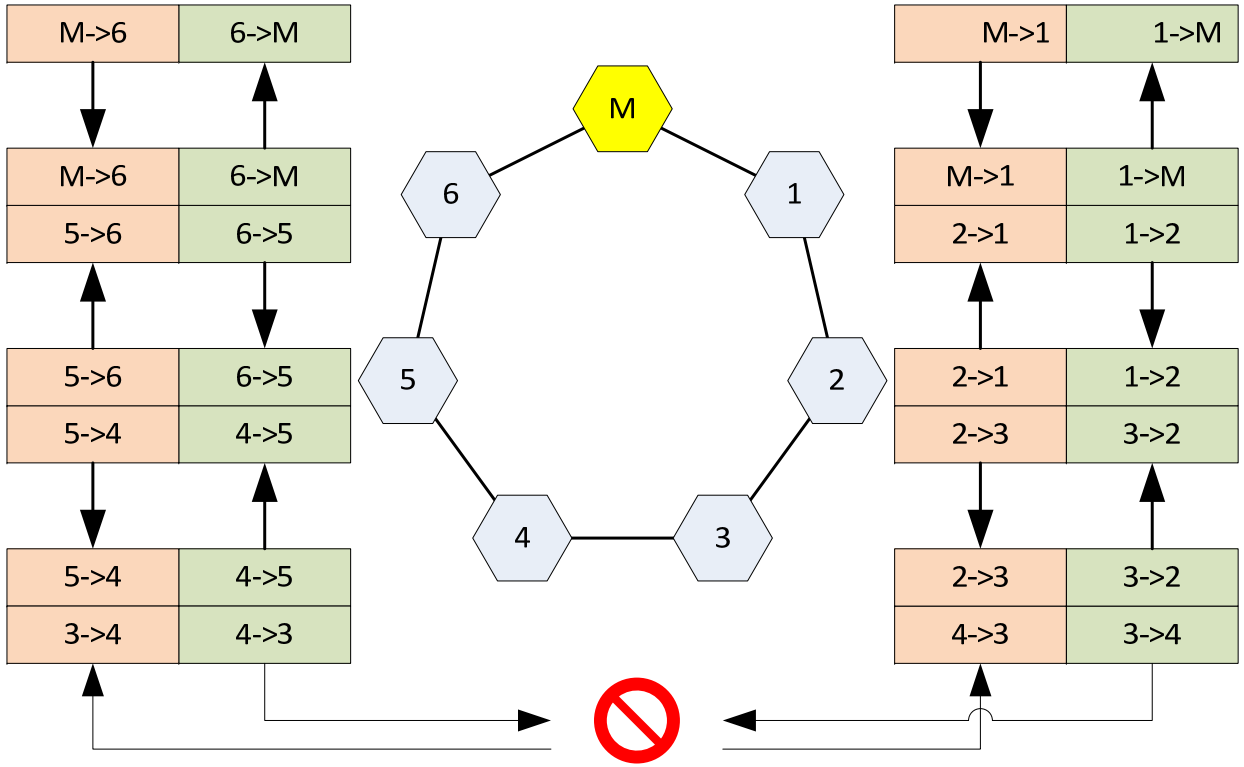




So: With 7 nodes in Round Robin – we are forced to deal with Gender; We chose to include Two-Gender Four-Gender and Eight-Gender cases

Round Robin & Gender

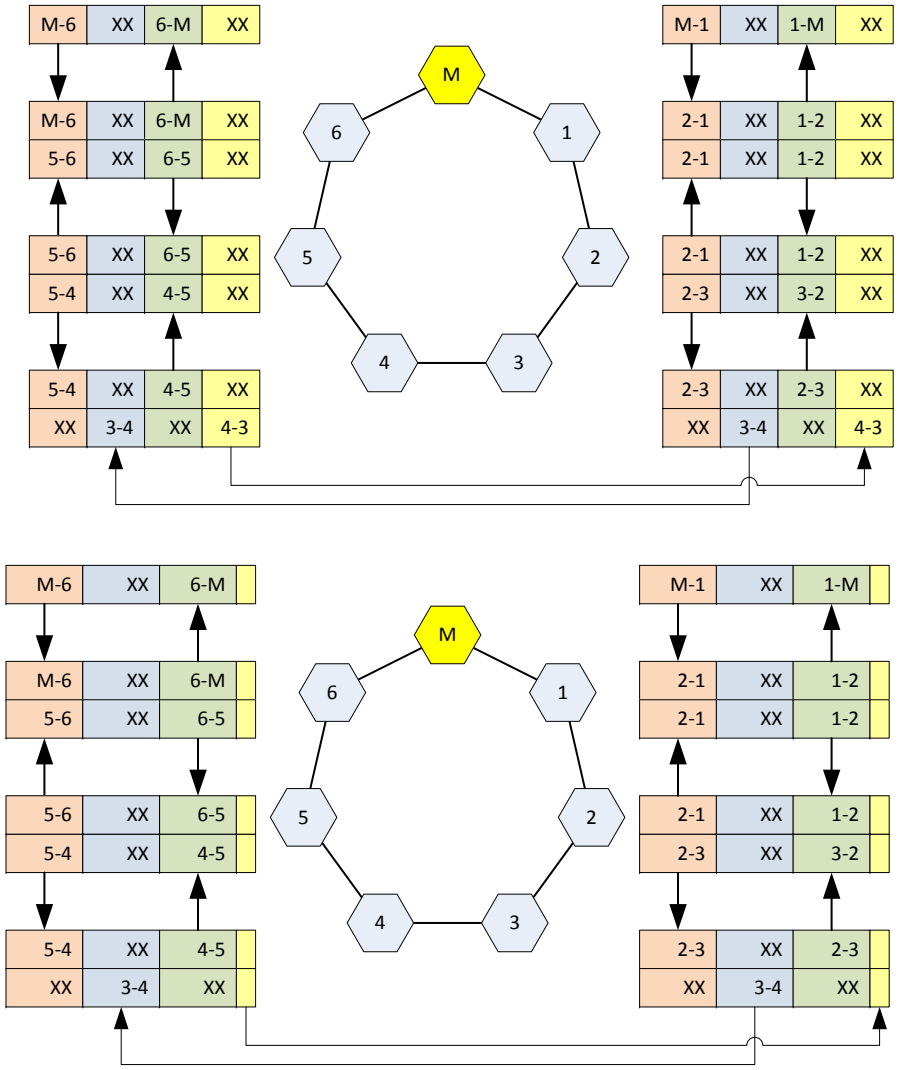
- With only two genders, a complete circuit cannot be created



If the link between 3 & 4 is omitted, all nodes can still be reached, but it affects the nature of data distribution

Round Robin & Gender (2)

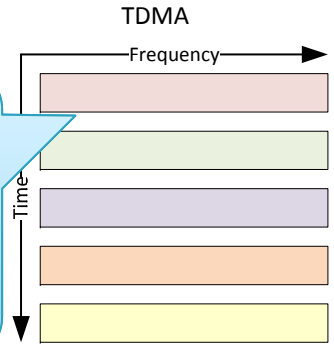
- Options:
  - 4-Gender System



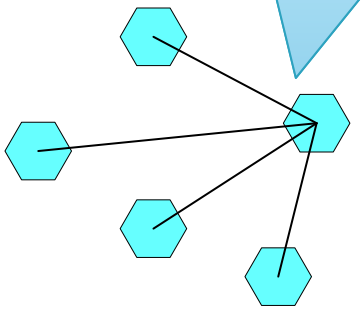
Generating Contrasts: TDMA

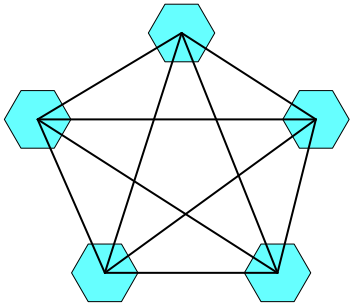
- Impacts on efficiency
  - Slot size
  - Topology
  - Network Diameter

If all communication goes to a single node, remote nodes can schedule their transmissions to arrive in the correct slot



guard bands per unit time

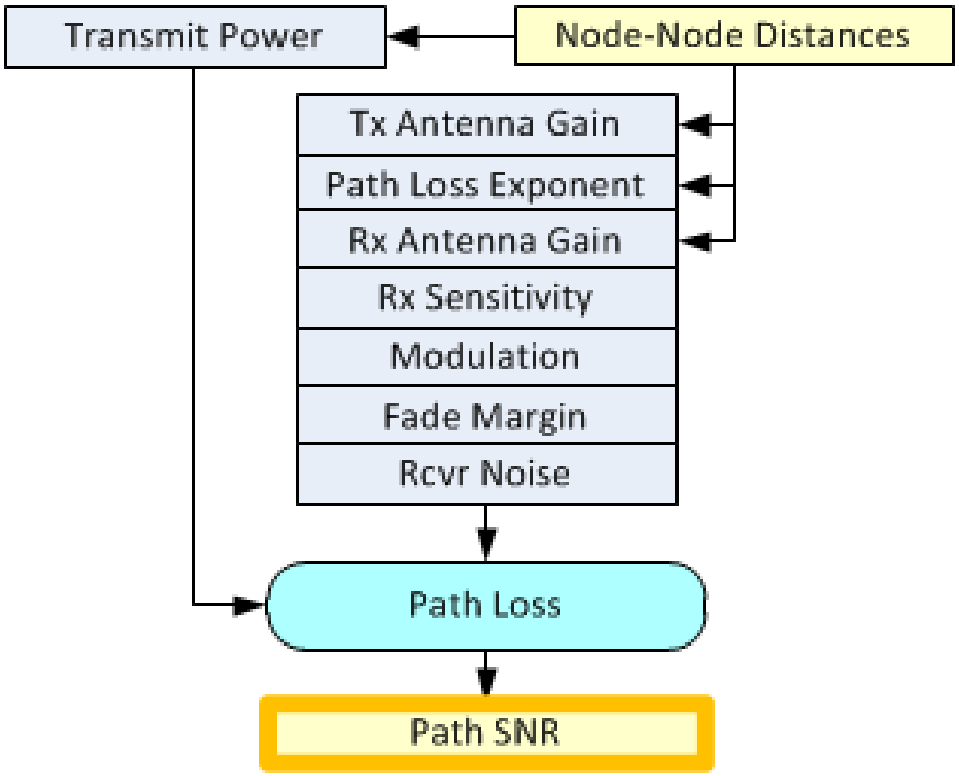




So: We chose to have widely varying network diameter

If communication is any to any, nodes must wait for the longest possible return path before beginning transmission – Network Diameter is important!

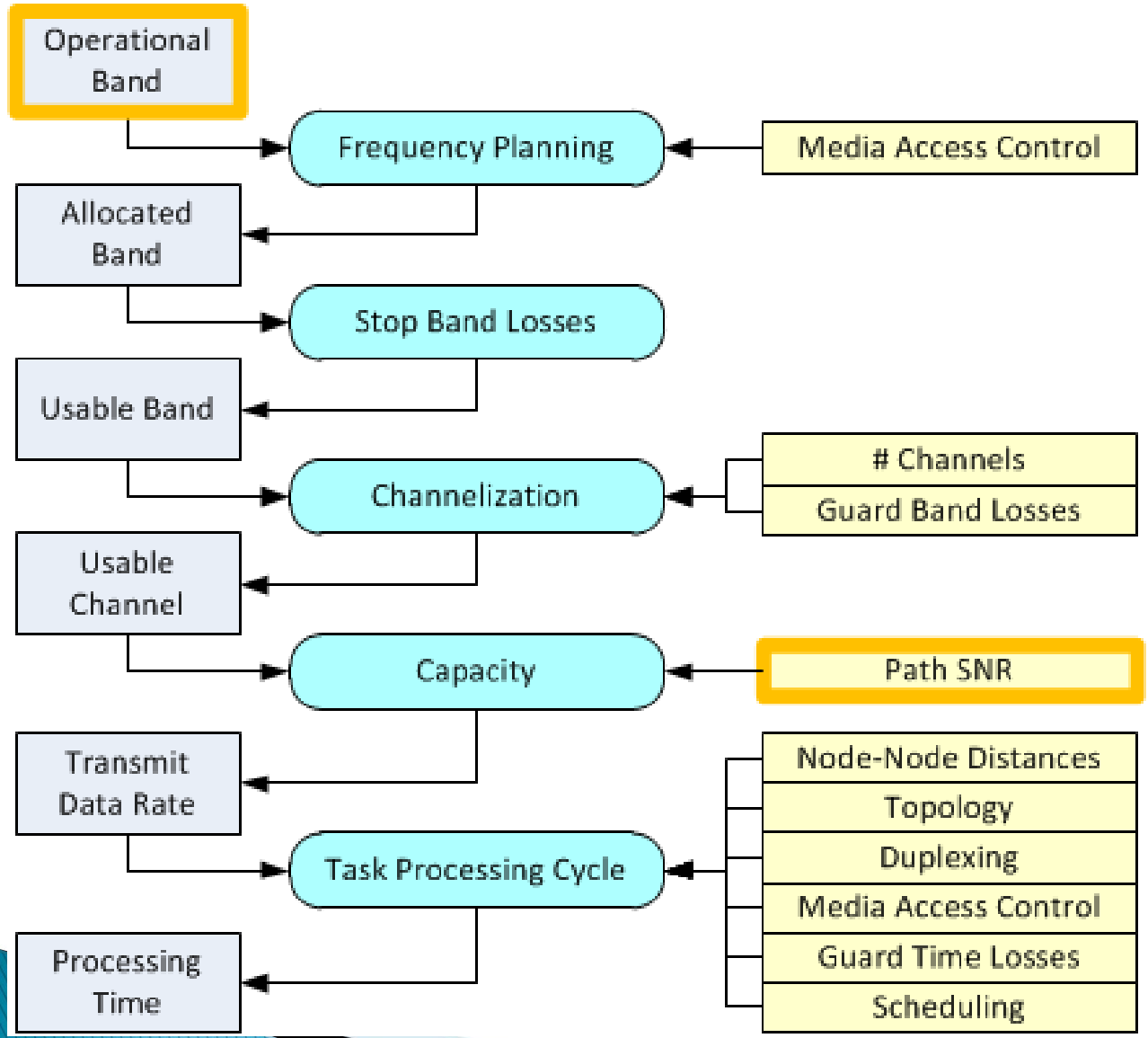
Calculation Philosophy (1)



- Ability to receive signal is based on receive SNR
- Drives maximum achievable data rates
- Solution is highly dependent on antennas

Tx & Rx Antenna Gain have large impacts on Path SNR. Long distance systems can still achieve high data rates because of higher antenna gains

Calculation Philosophy (2)



- Losses occur at several steps in the process
- Each MAC protocol has a slightly different impact

Guard Band Calculations

FDMA Guard Bands

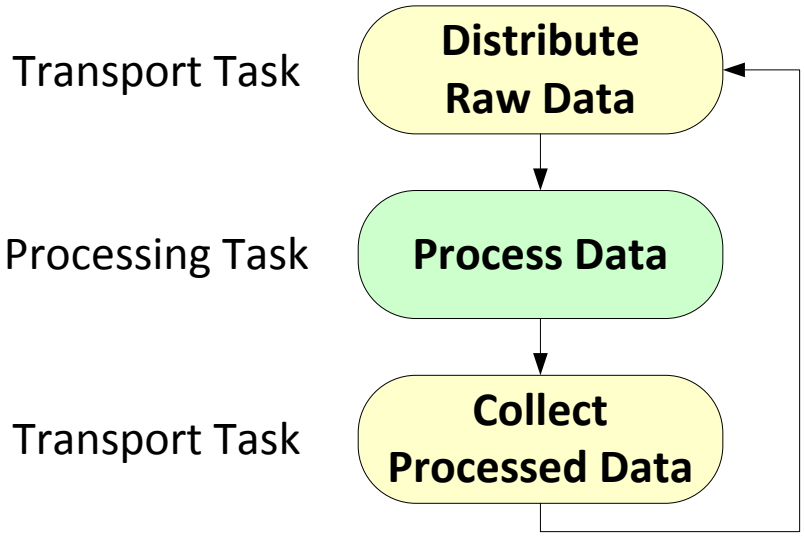
Distance	100m	100 km	500 km
Frequency	2 GHz	11 GHz	11 GHz
Bandwidth	10 MHz	10 MHz	10 MHz
Speed	3 m/s	250Miles/Hr (111.76m/s)	7000 m/s
Doppler Shift	20 Hz	745 Hz	46,669 Hz
Drift and Wander [2]	65 Hz	100 Hz	150 Hz
Guard band	85 Hz	845 Hz	46,819 Hz

TDMA Guard Times

Distance	100m	100 km	500 km
Frequency	2 GHz	11 GHz	11 GHz
Bandwidth	10 MHz	10 MHz	10 MHz
Speed	3 m/s	111.76m/s	7000 m/s
Guard bands	0.333 usec	333.333 usec	1666.6667 usec

Calculation Philosophy (3)

- Is there a point where increasing processing power provides no additional gains?

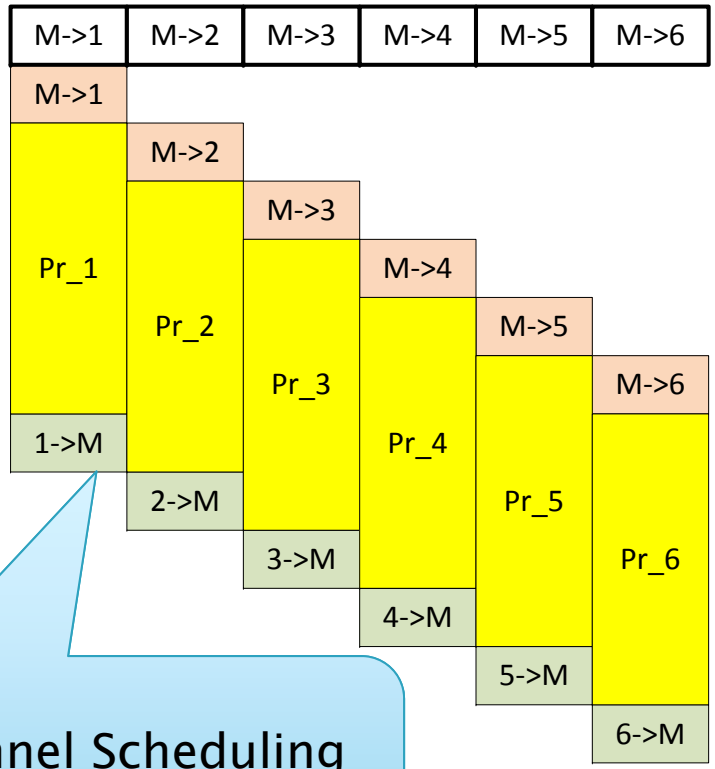


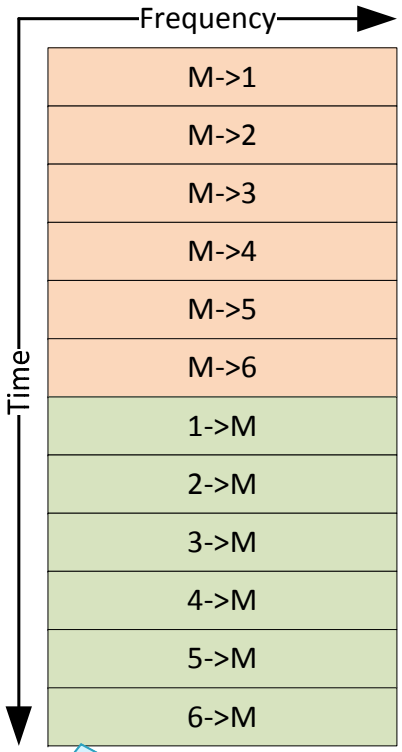
When time needed to transport data becomes as large as (or larger than) time needed to process data the system becomes transport limited.

At the cross-over point, we can calculate the minimum processor load factor (i.e. the minimum complexity in seconds/MByte of raw data) needed to keep the processor fully occupied

Example Cases

- Hub/Spoke: TDD/TDMA One sender at a time





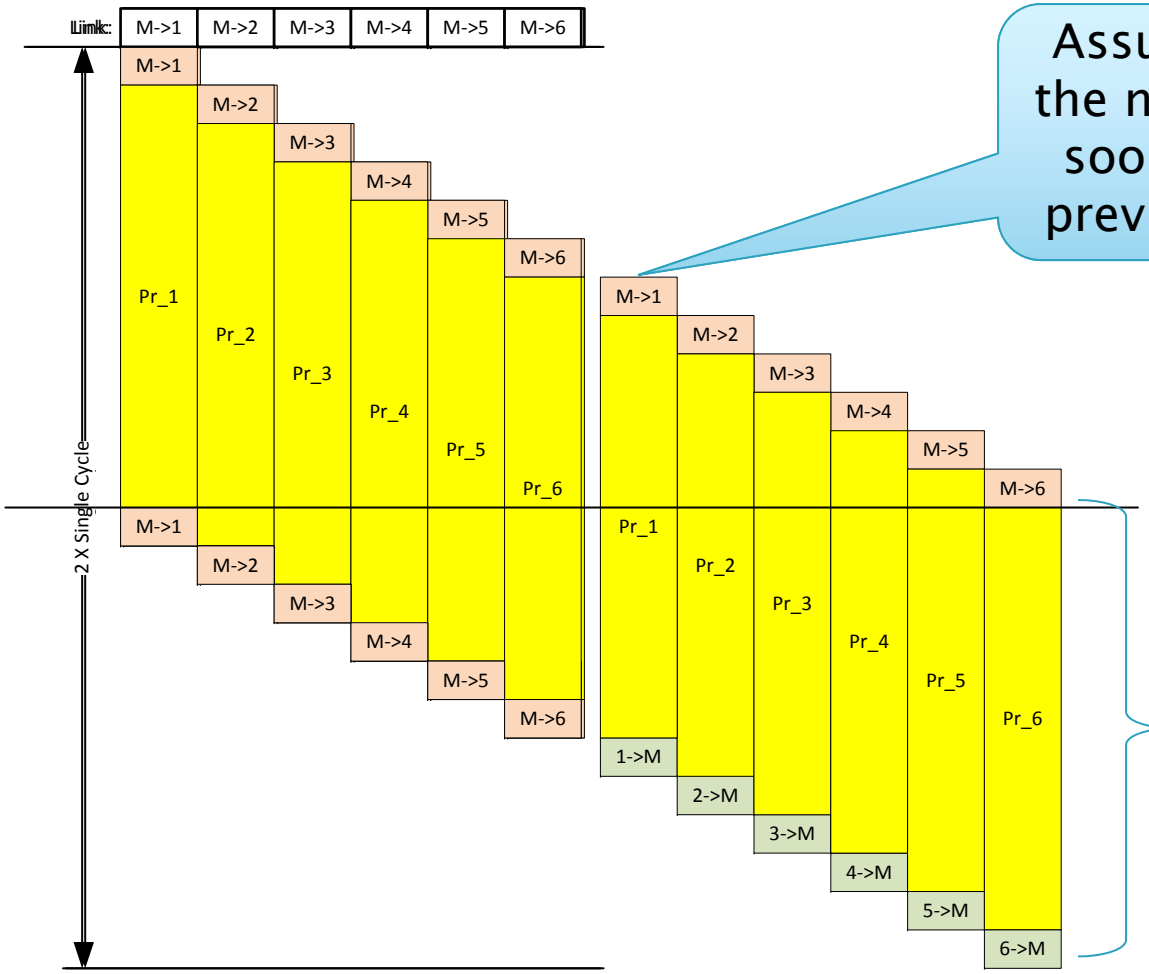
Channel Scheduling Constraints

Time & Frequency Constraints

Metric Selection

- Requirements
  - Needs to show impact of resource allocation forced by MAC protocol and Topology
  - Needs to show impact of scheduling within channel
- Discarded Options
  - Data Rate (Doesn't show scheduling impact)
  - Guard Time Fraction (Doesn't show scheduling)
  - Families of curves showing data rates for various case (Too cumbersome)
- Selected Option
  - Point at which transport time = processing time
    - Accommodations: Assume constant ratio of bytes outbound to processed bytes

Example: Transport = Processing

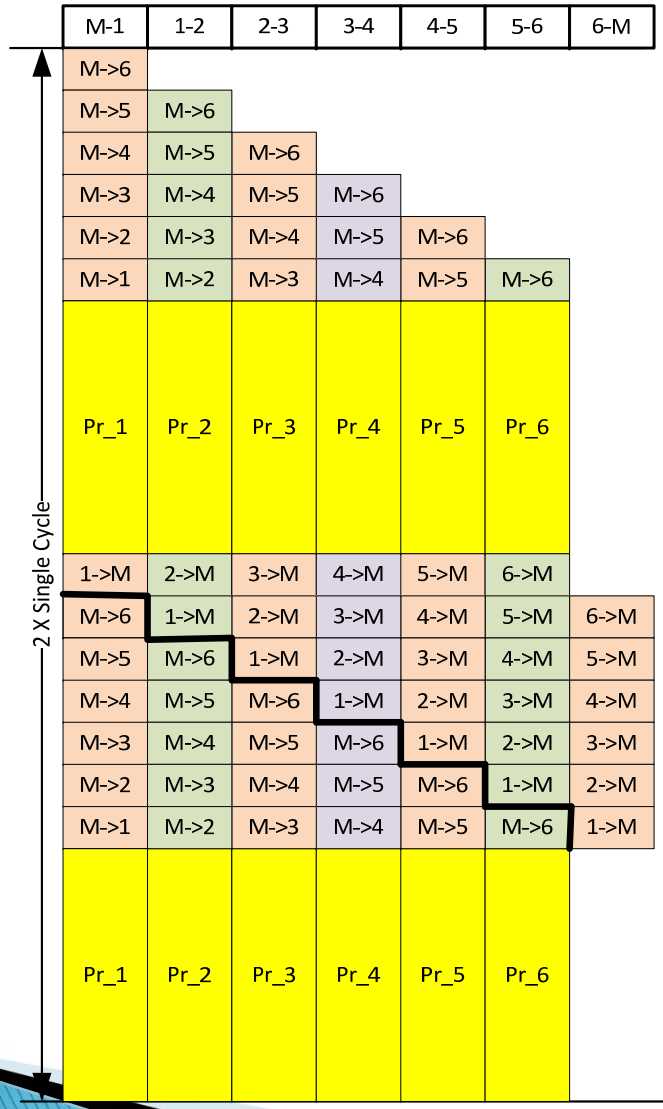


Assume that Transport of the next cycle can begin as soon as Transport of the previous cycle is complete

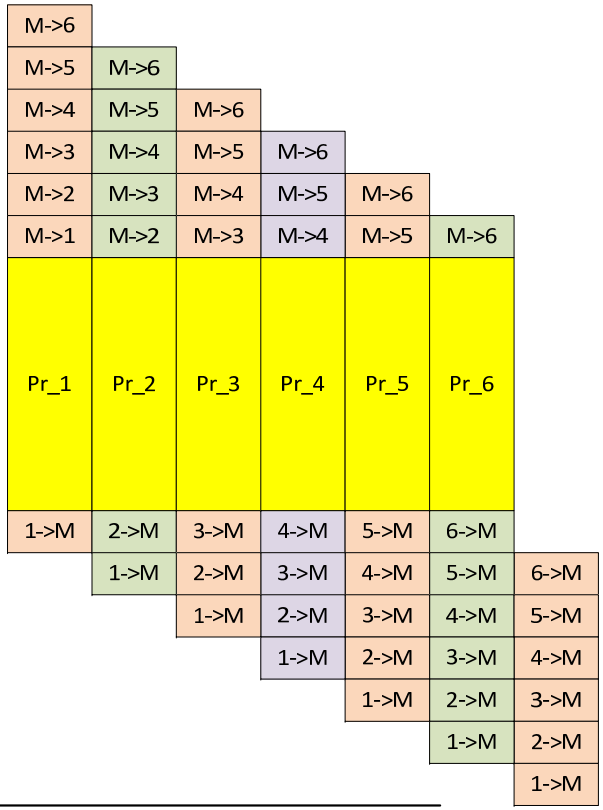
Total Transport Time = Total Processing Time

- When Transport Time = Processing Time the system can exploit the maximum processing power

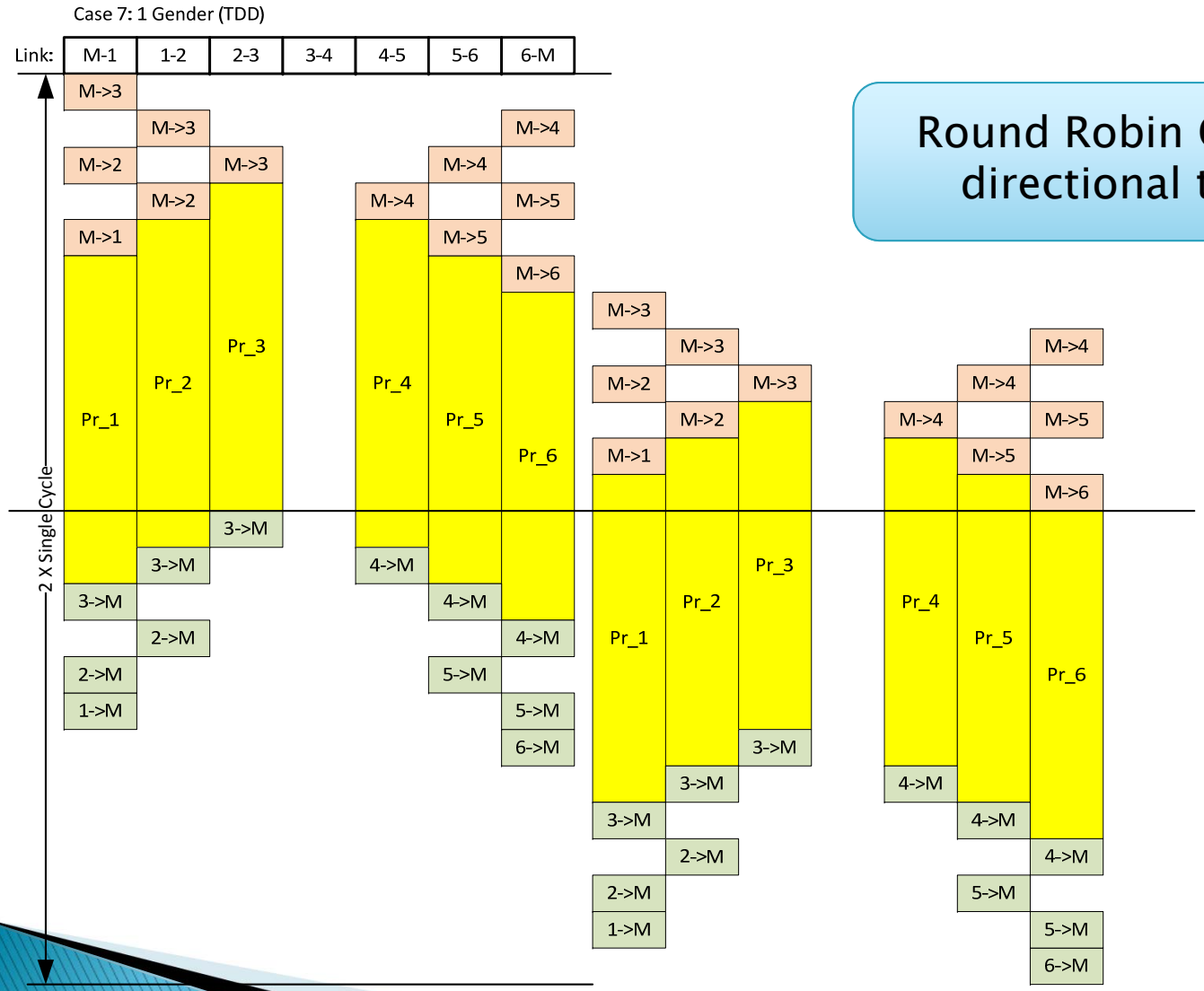
Example: Transport = Processing



Round Robin Case with uni-directional traffic flow



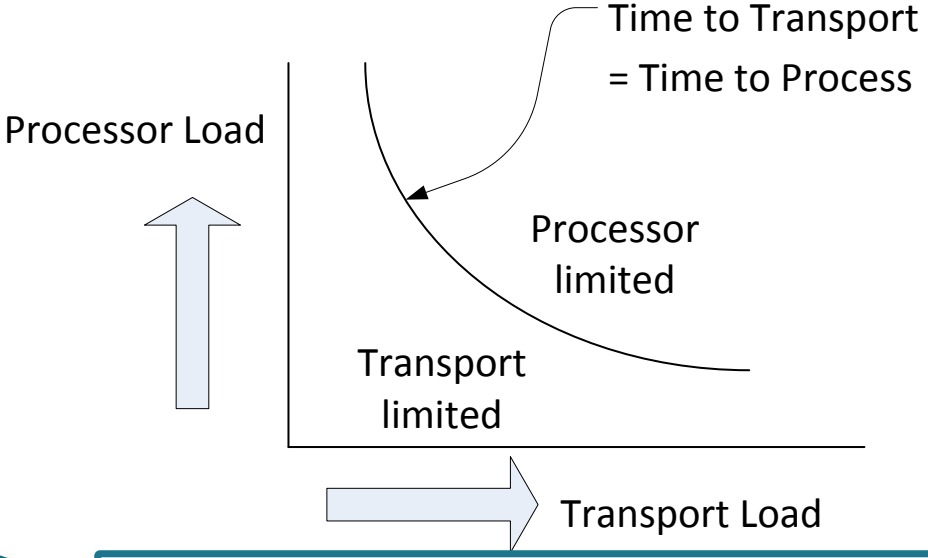
Example: Transport = Processing

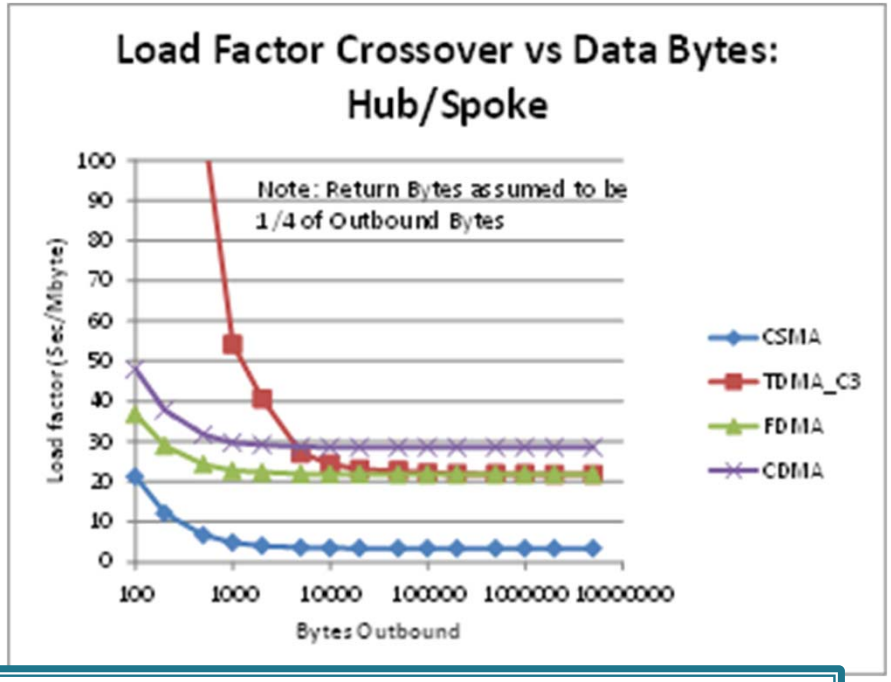


Round Robin Case with b-directional traffic flow

Interpreting Plots

- Dimensions: Processor Load & Transport Load
  - Metric chosen for transport load was bytes outbound (actually a surrogate)
  - Metric chosen for processor load is referenced to it





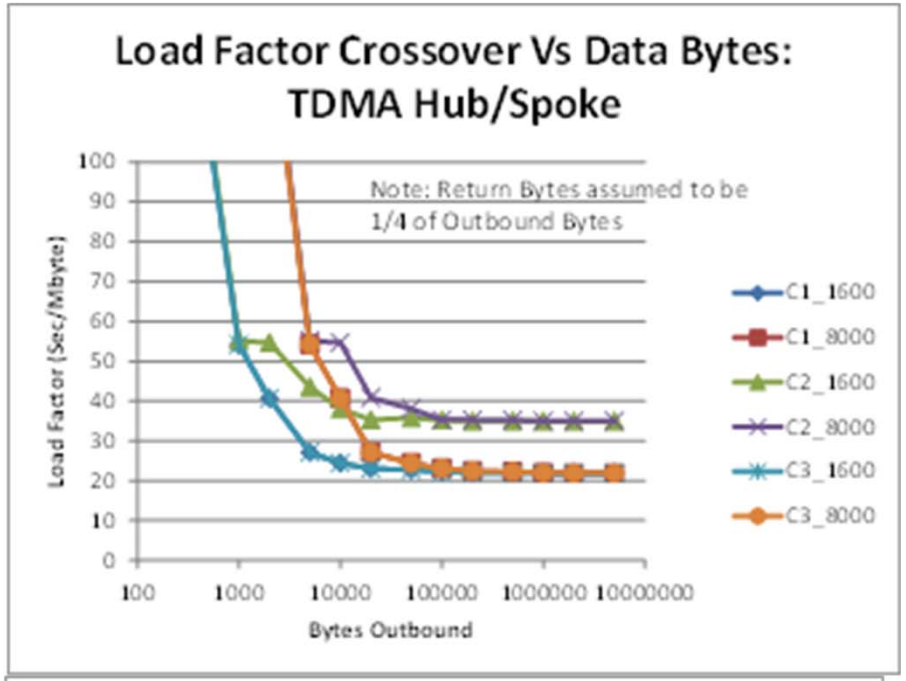
Future work? Bytes Outbound/Processed Bytes not constant?
How valid is comparison as we move away from crossover plot?

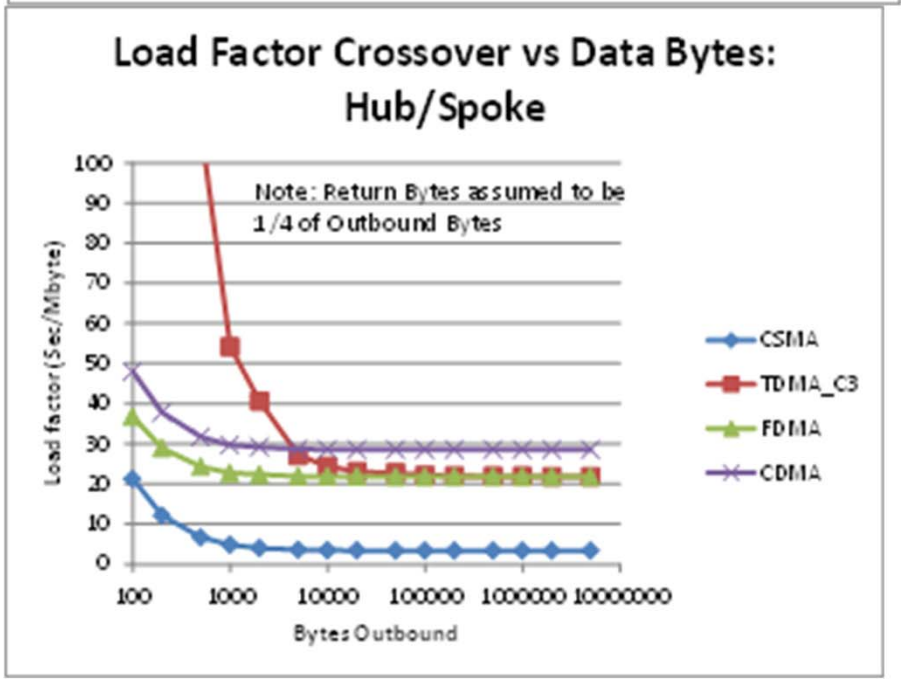
Hub/Spoke

- Plot Load Factor vs Bytes outbound

Interpretation: Curve represents intensity of processing operation needed to keep the processor fully loaded when the transport channel is full.

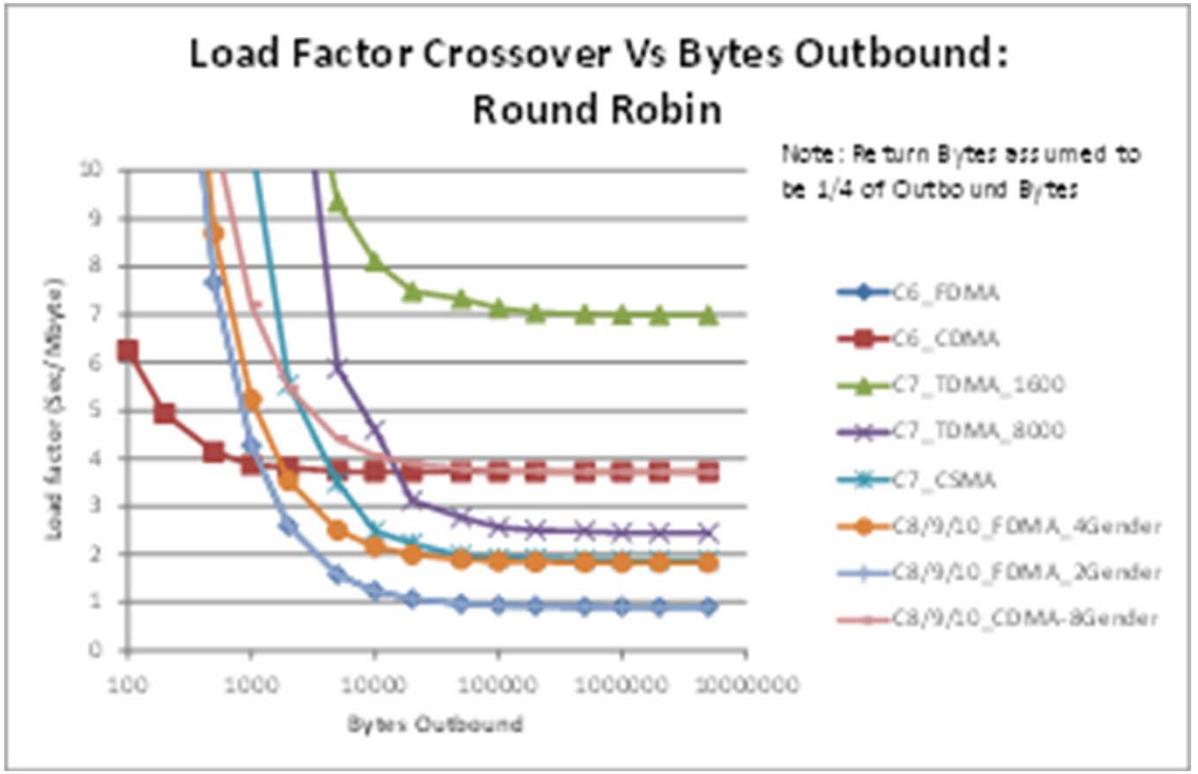
Wireless Distributed Computing System won't operate below the curve





Round Robin

- Plot Load Factor vs bytes outbound



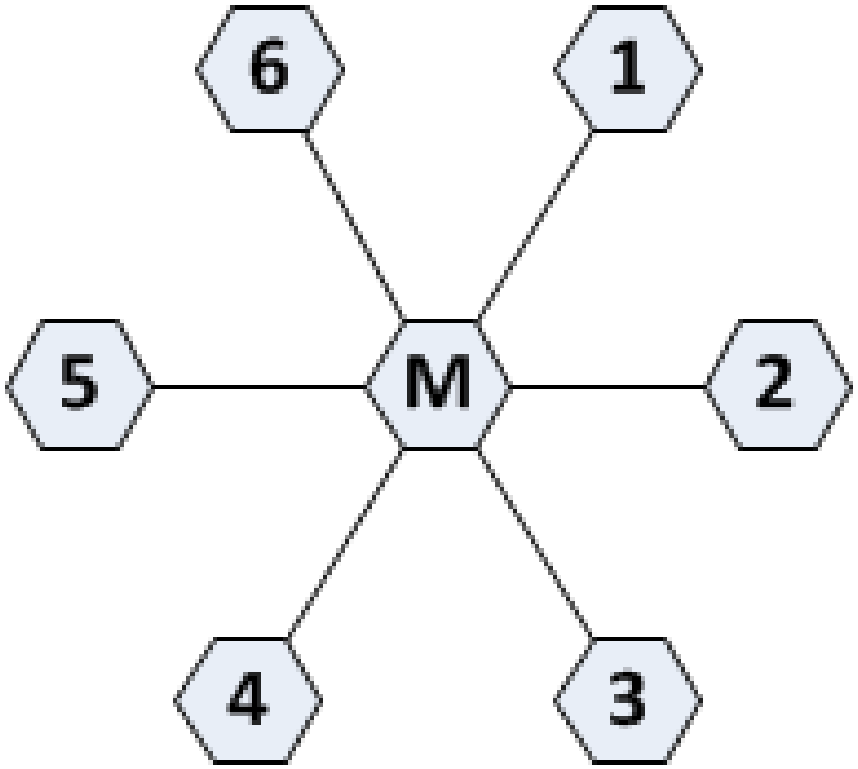
Conclusions

- MAC Protocol impact on WDC efficiency can be seen by plotting the Load factor crossover point
- Most things, including distance, can be overcome, but Channel contention is an enemy to WDC applications
  - Some protocols are better suited for distance and topology situations because of guard time or guard band constraints

Backup Slides

Hub / Spoke

- Channel is common to all nodes



Example Cases

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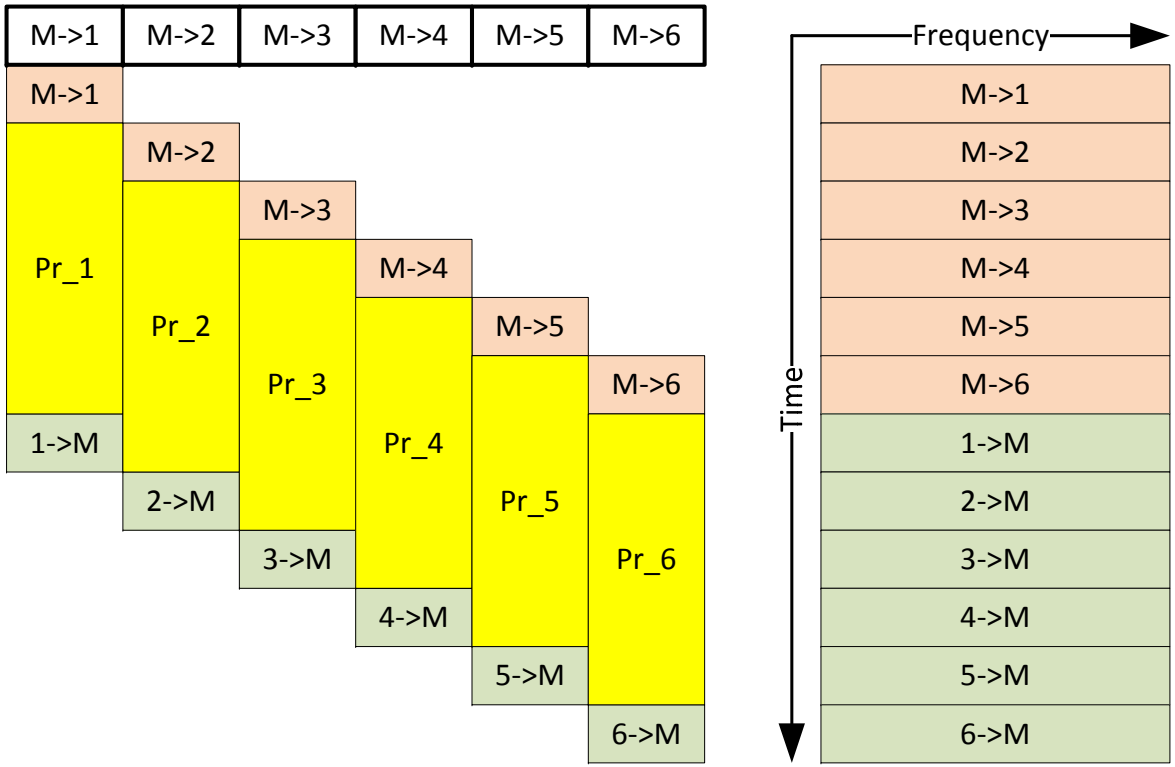
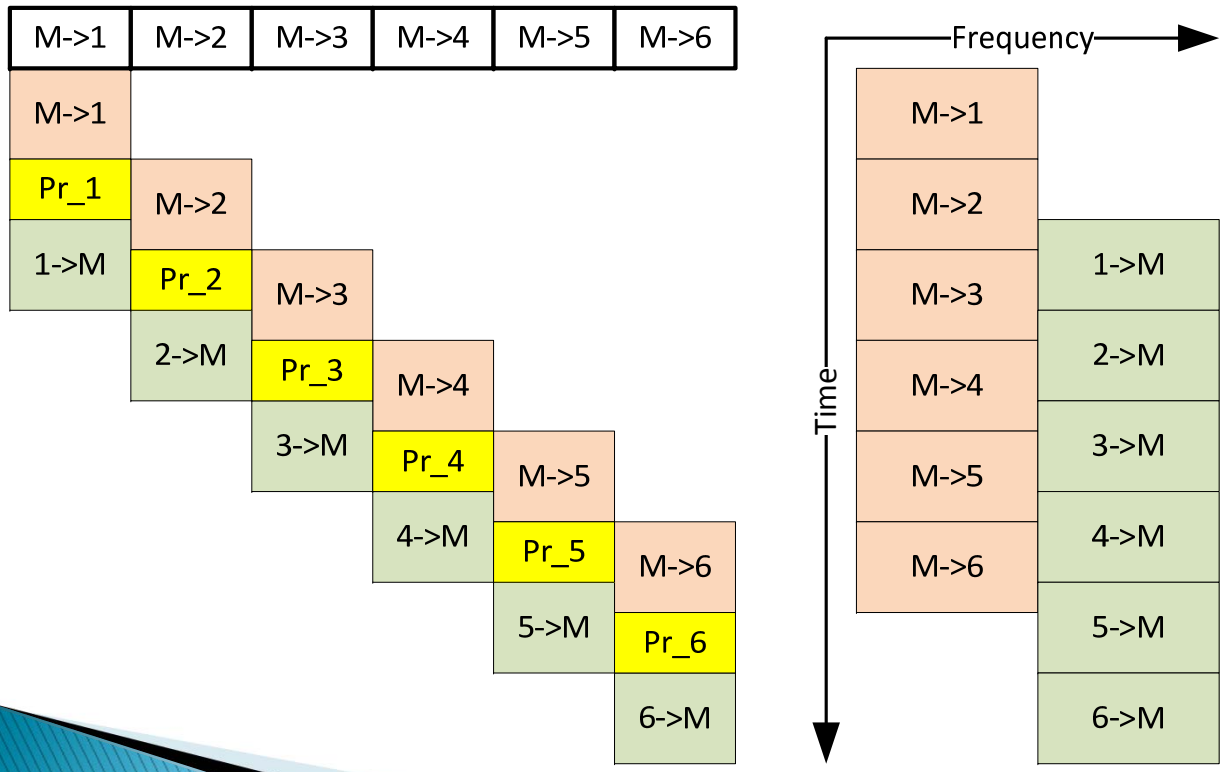


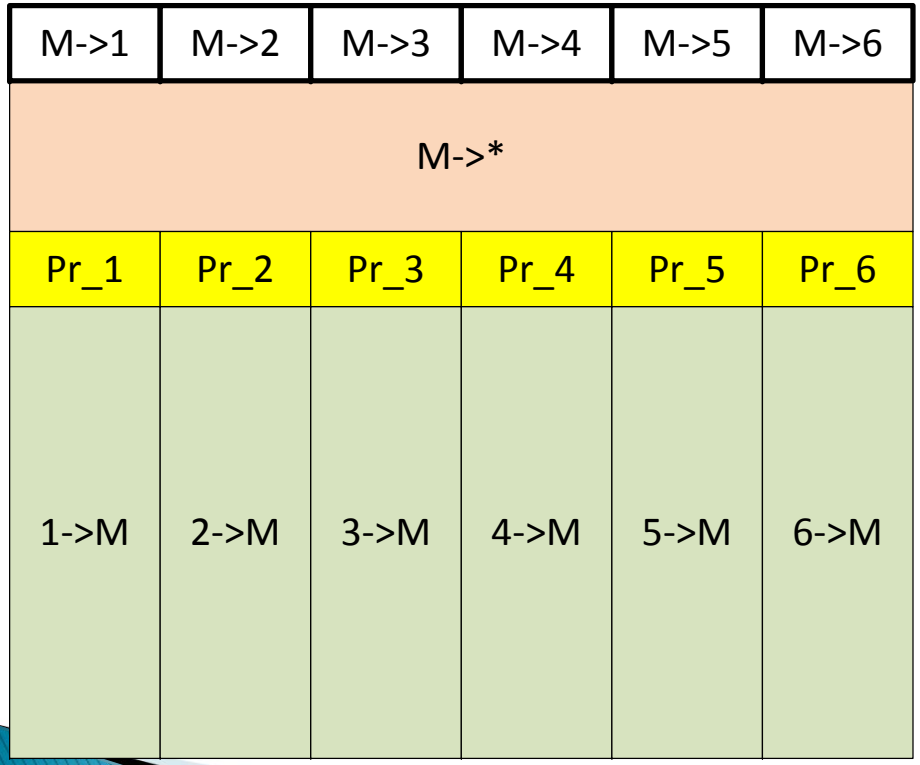
Example Cases FDD/TDMA

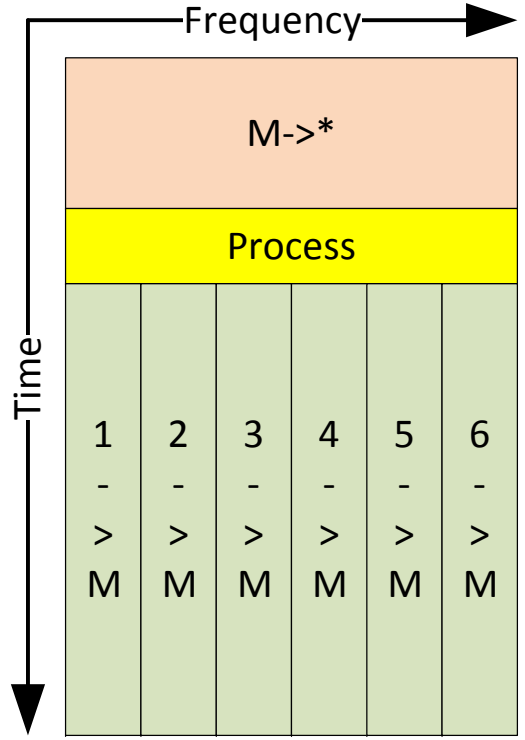
- Hub/Spoke: Unique Send/Receive but FDD vs TDD



Example Cases: FDD/FDMA

- Hub/Spoke: Common Send / Unique Receive

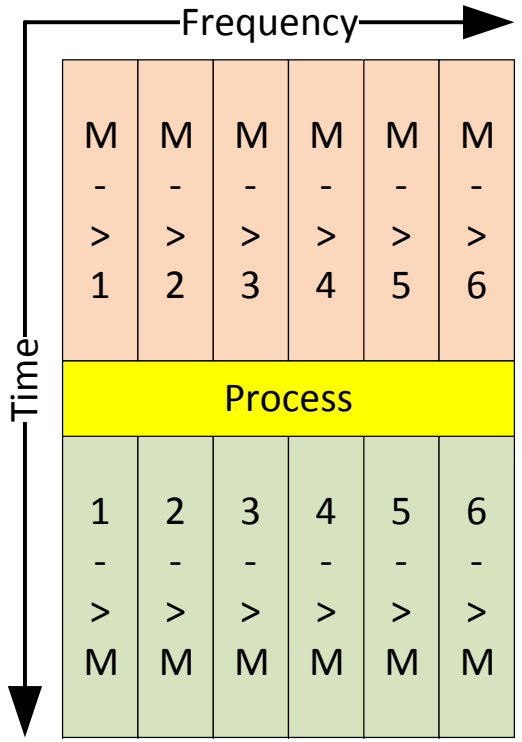




Example Cases: CDMA

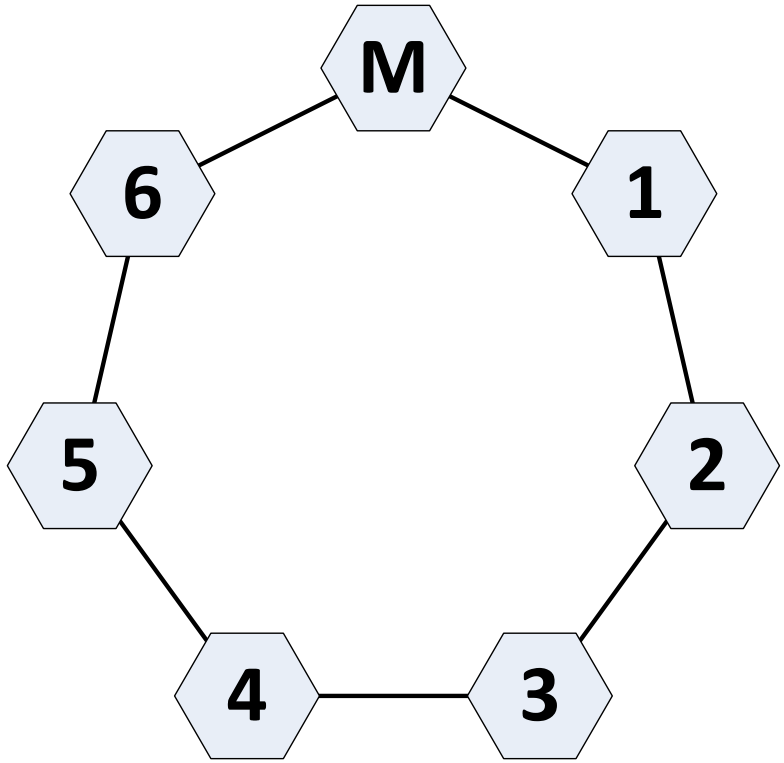
- Hub/Spoke: Send/Receive Unique

M->1	M->2	M->3	M->4	M->5	M->6
M->1	M->2	M->3	M->4	M->5	M->6
Pr_1	Pr_2	Pr_3	Pr_4	Pr_5	Pr_6
1->M	2->M	3->M	4->M	5->M	6->M



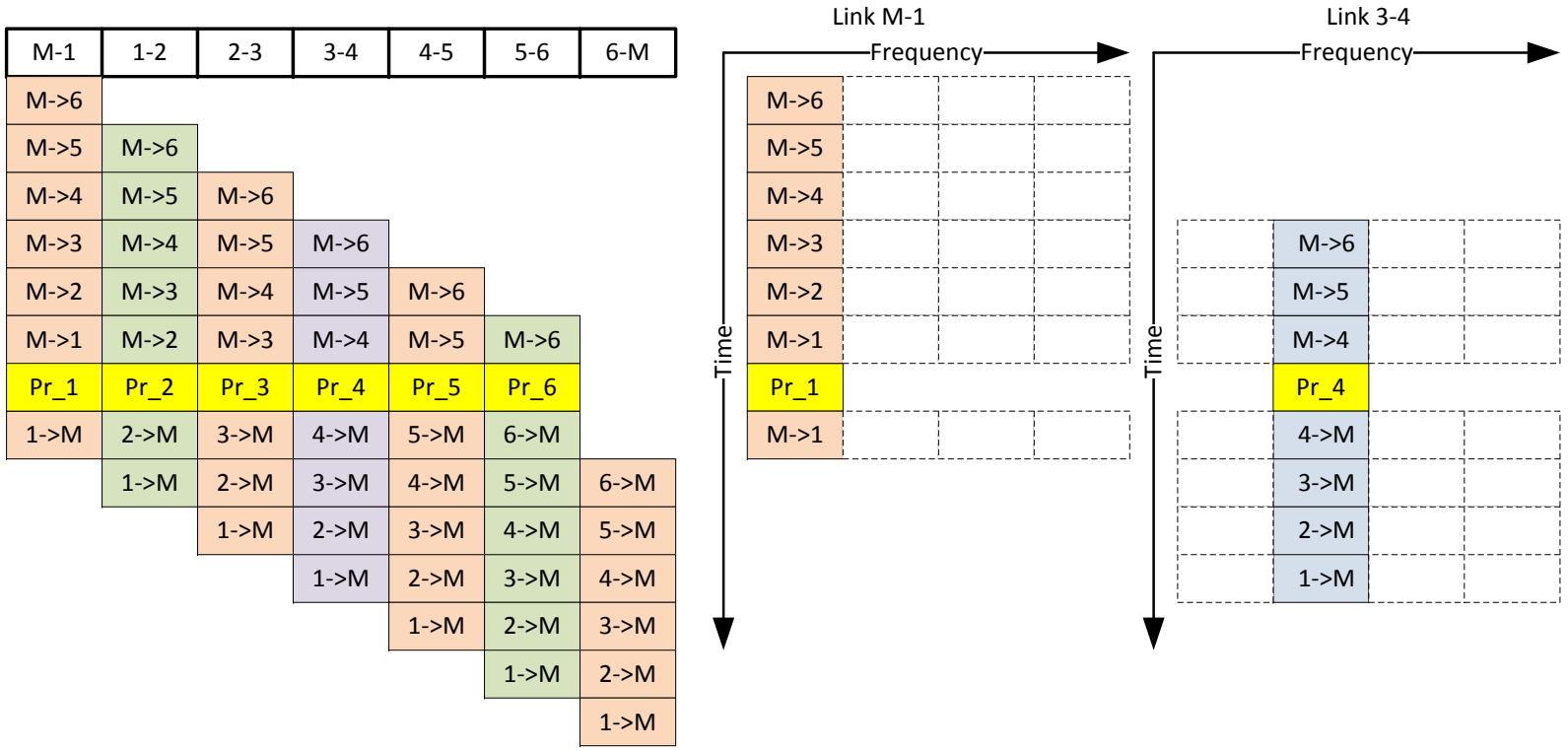
Round Robin

- Channel is unique between each node, subject to gender constraints



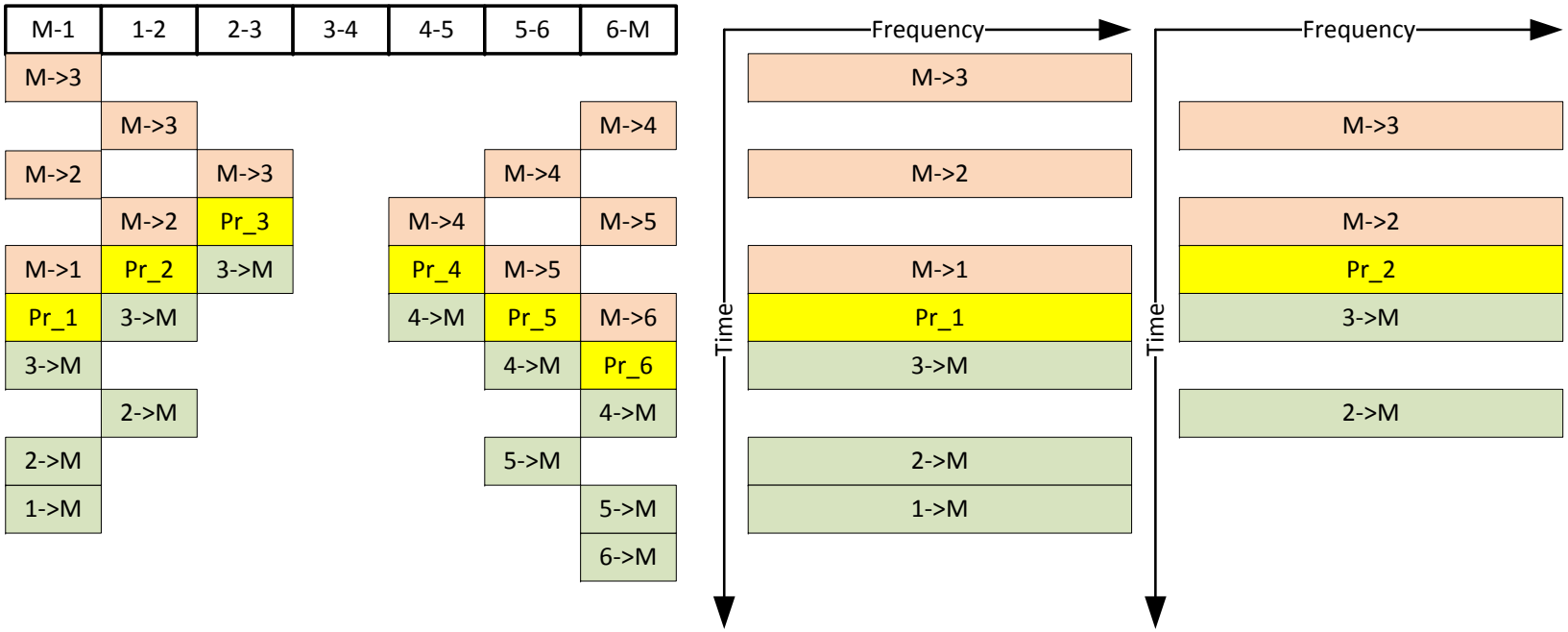
Example Cases

- Round Robin 4-Gender FDMA / 8 Channel CDMA



Example Cases

- Round Robin TDD



Example Cases

- Round Robin FDD

Channel Sequencing

M-1	1-2	2-3	3-4	4-5	5-6	6-M
M->3						M->4
M->2	M->3				M->4	M->5
M->1	M->2	M->3		M->4	M->5	M->6
Pr_1	Pr_2	Pr_3		Pr_4	Pr_5	Pr_6
1->M	2->M	3->M		4->M	5->M	6->M
2->M	3->M				4->M	5->M
3->M						4->M

Time & Frequency Allocation Options