NoCs 2008

Real-Time Communication Analysis for NoCs with Wormhole Switching

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Outline

1. QoS in NoC
2. Priority based wormhole switching
3. Worst case network latency analysis
4. Conclusion

Networks on Chip (NoC)

- On-chip Communication:
  - Point-to-Point
  - Bus
- NoC: packet-switched, shared, optimized for communications
  - Resource efficiency
  - High scalability
  - IP reusability
  - High performance

NoC needs QoS

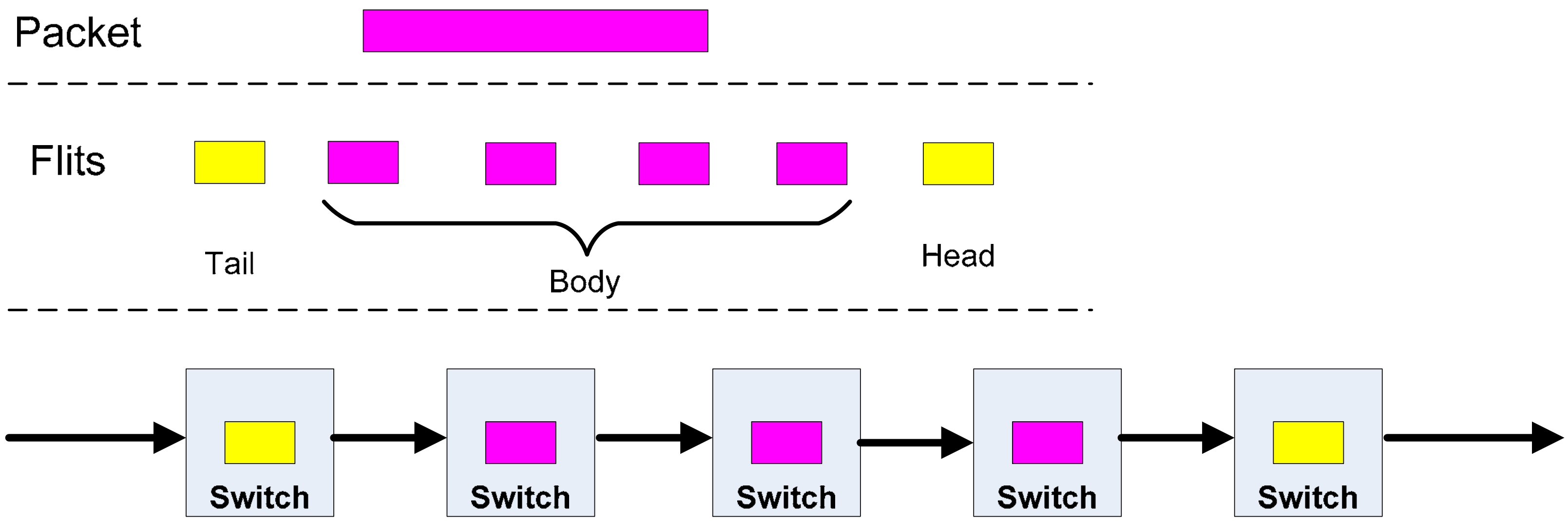
- Differentiated Service Requirement
  - Best Effort
  - Guaranteed Service
- Performance parameters:

  latency, bandwidth, bounded jitter and loss probability, in-order data, etc.
- Real-Time Service:
  - The correctness relies on not only the communication result but also the completion time bound (deadline).
  - For hard real-time service, it is necessary that all the packets must be delivered before their deadlines even under worst case scenario.

Several Solutions

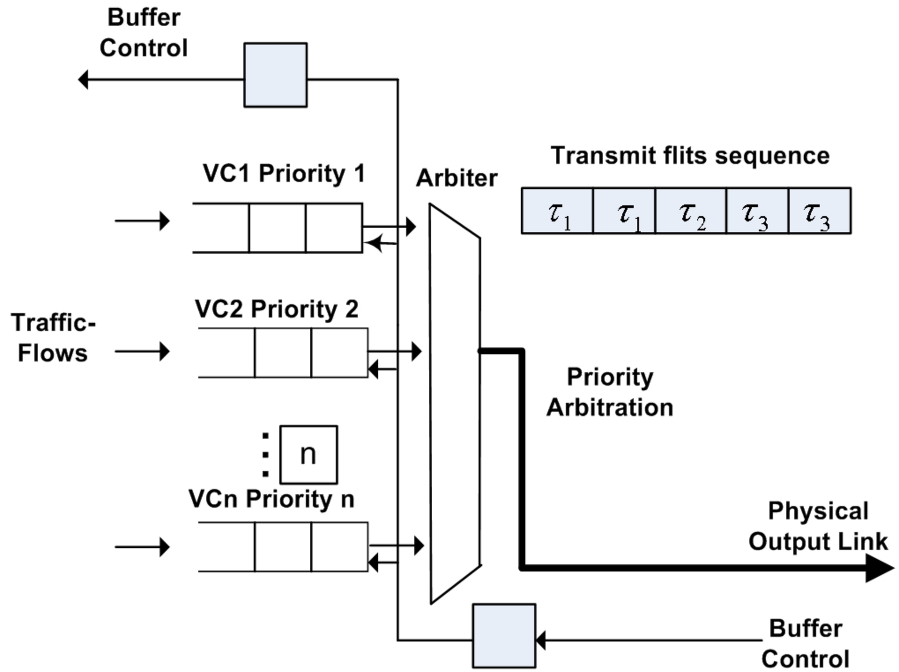
- **Contradiction:** The network gives more efficiency and flexibility but introduces the unpredictable delay due to the contention. Real-time service, requires the timing to be predictable even under the worst case situation
- **Contention avoidable**
  - Circuit Switching : aSoC
  - TDM : AEtheral, Nostrum
- **Contention acceptable**
  - Priority based Wormhole Switching

Wormhole Switching



- Advantages (with Virtual Channels)
  - Small Buffer Size
  - High Throughput
  - Low Average Latency

Priority Router Structure



- There are sufficient VCs at each router
- Each VC is assigned distinct global priority
- Each flow also has distinct priority
- Flow only requests the VC with same priority
- At any time, only the flit with highest priority can access the output link
- Flit-level priority preemption between different VCs

System Model

Characterize traffic-flow

- A traffic-flow is packet stream which traverses the same route from source to destination and requires the same grade of service.

Attribute

- P : Priority
- C : Basic network latency
- T : Period for periodic flow or minimal interval for sporadic flow
- D : Deadline
- J^R : Release Jitter

Interrelationship

- Direct competing: $Path(\tau_i) \cap Path(\tau_j) \neq \phi$

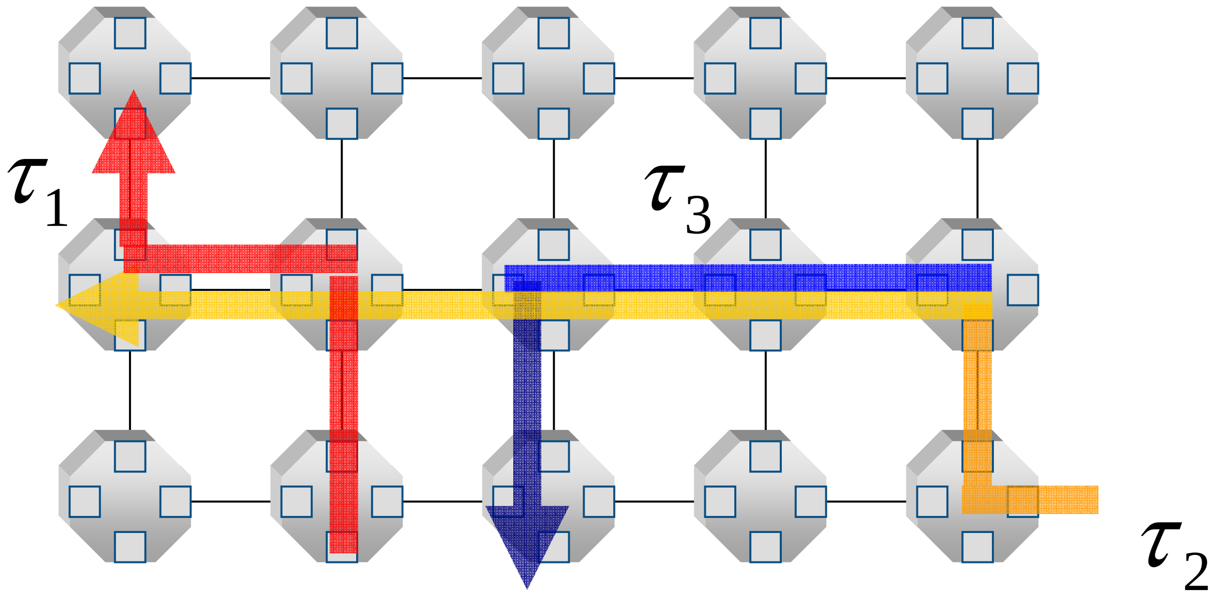
  direct interference set: $S_i^D = \{\forall \tau_j \mid Path(\tau_i) \cap Path(\tau_j) \neq \phi, P_j > P_i\}$
- Indirect competing:

  $Path(\tau_i) \cap Path(\tau_j) \neq \phi, Path(\tau_j) \cap Path(\tau_k) \neq \phi, Path(\tau_i) \cap Path(\tau_k) = \phi$

  indirect interference set

$$S_i^I = \{\forall \tau_k \mid Path(\tau_i) \cap Path(\tau_j) \neq \phi, Path(\tau_j) \cap Path(\tau_k) \neq \phi, Path(\tau_i) \cap Path(\tau_k) = \phi, P_k > P_j > P_i\}$$

Wormhole Switching- A Case



Priority ordering:

$$P_1 > P_2 > P_3$$

$$S_1^D = \phi, S_1^I = \phi$$

$$S_2^D = \{\tau_1\}, S_2^I = \phi$$

$$S_3^D = \{\tau_2\}, S_3^I = \{\tau_1\}$$

Characterize Network Latency

- Worst case network latency R :
  - The maximum length of time the packet could take to travel from source to destination
  - The flow is schedulable if $R \leq D$
- Basic network latency C :

  the network latency happens when there no traffic-flow contention exists.

$$C = \left\lceil \frac{L_{\max} + L_{add}}{f_{size}} \right\rceil \cdot f_{size} / B_{link} + Hop \cdot S$$

Model and Assumption

- The physical communication links are treated as shared competition resource
- At any time, only one traffic-flow is permitted to access the shared path
- The packet moves ahead when gets highest priority along the path
- The arrivals of higher priority flows are considered as preemption interference
- The allowable service time for a flow is all the time interval at which no higher priority flow competes for the same physical link

Network Latency Evaluation(1)

- Worst Case Network Latency:

$$R_i = C_i + I_i$$

R_i : worst case latency

I_i : maximum interference

the packets is supposed with maximum length and released at maximum rate

$$I_i = \sum_{\forall j \in S_i^D} \left\lceil \frac{R_i + J_j^R}{T_j} \right\rceil C_j$$

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Network Latency Evaluation(2)

- Worst case network latency equation

$$R_i = C_i + \sum_{\forall j \in S_i^D} \left\lceil \frac{R_i + J_i^R}{T_j} \right\rceil C_j$$

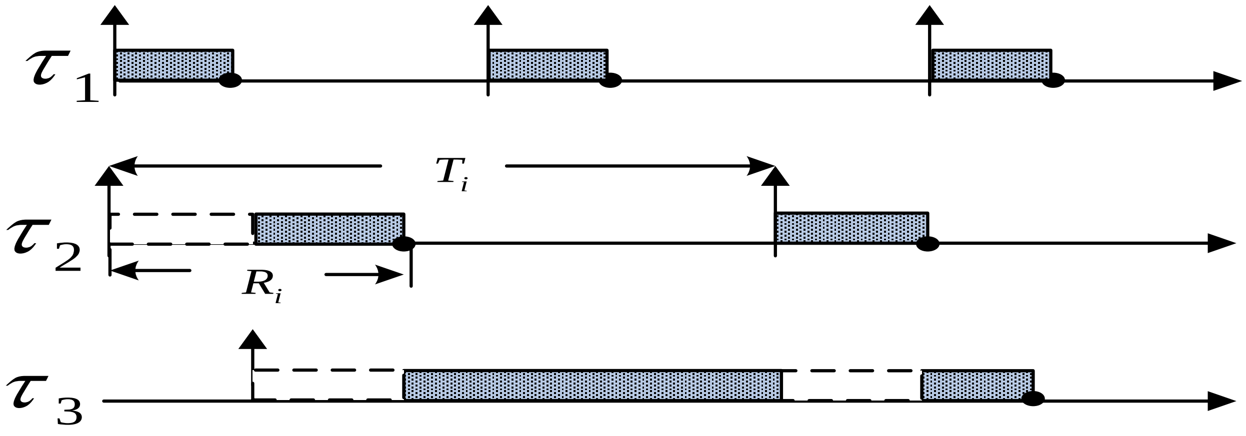
The eqaution is solved using iterative technique

$$R_i^{n+1} = C_i + \sum_{\forall j \in S_i^D} \left\lceil \frac{R_i^n + J_i^R}{T_j} \right\rceil C_j$$

Iterative starts with $R_i^0 = C_i$
and terminates when $R_i^{n+1} = R_i^n$
or $R_i^{n+1} > D_i$ which denotes the deadline miss for this flow.

Consider Indirect Interference (1)

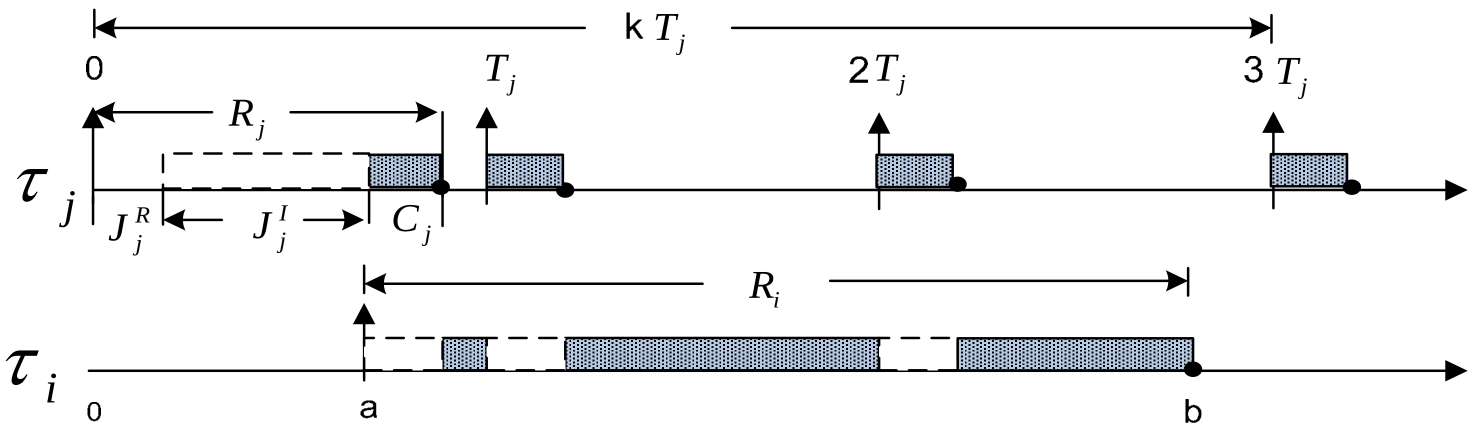
- Minimal interval between subsequent preemption is less than period



- This could happen only when indirect interference is considered.

Consider Indirect Interference (2)

- Preemption interference upper bound



$$I_i = \sum_{\forall j \in S_i^D} \left\lceil \frac{R_i + J_j^R + R_j - C_j}{T_j} \right\rceil C_j$$

- Worst case latency

$$R_i = C_i + \sum_{\forall j \in S_i^D} \left\lceil \frac{R_i + J_i^R + R_j - C_j}{T_j} \right\rceil C_j$$

Case Example

Trafffic-Flows	C	P	T	D
τ_1	2	1	6	6
τ_2	3	2	7	7
τ_3	3	3	13	13

- For τ_1 : there is no higher priority flow than τ_1 , so $R_1 = C_1 = 2$

- For τ_2 : τ_2 shares the physical link with higher priority flow τ_1 and $S_2^D = \{\tau_1\}, S_2^I = \phi$

$$R_2^0 = 3$$

$$R_2^1 = 3 + \left\lceil \frac{3}{6} \right\rceil 2 = 5$$

$$R_2^2 = 3 + \left\lceil \frac{5}{6} \right\rceil 2 = 5$$

- τ_3 suffers both direct and indirect interference with $S_3^D = \{\tau_2\}, S_3^I = \{\tau_1\}$

The interference jitter of τ_2 referred to τ_3 equals $R_2 - C_2 = 5 - 3 = 2$

So

$$R_3 = C_3 + \left\lceil \frac{R_3 + R_2 - C_2}{T_2} \right\rceil C_2$$

which stops at $R_3 = 9$

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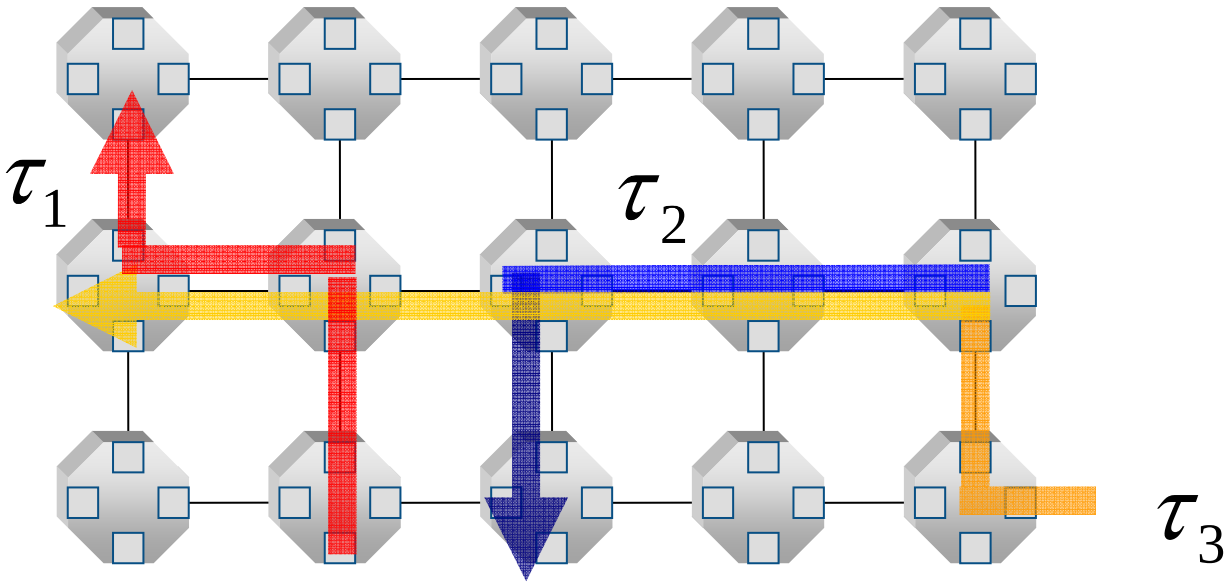
Tightness of analysis (1)



Priority ordering:

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$$S_2^D = \phi, S_2^I = \phi$$

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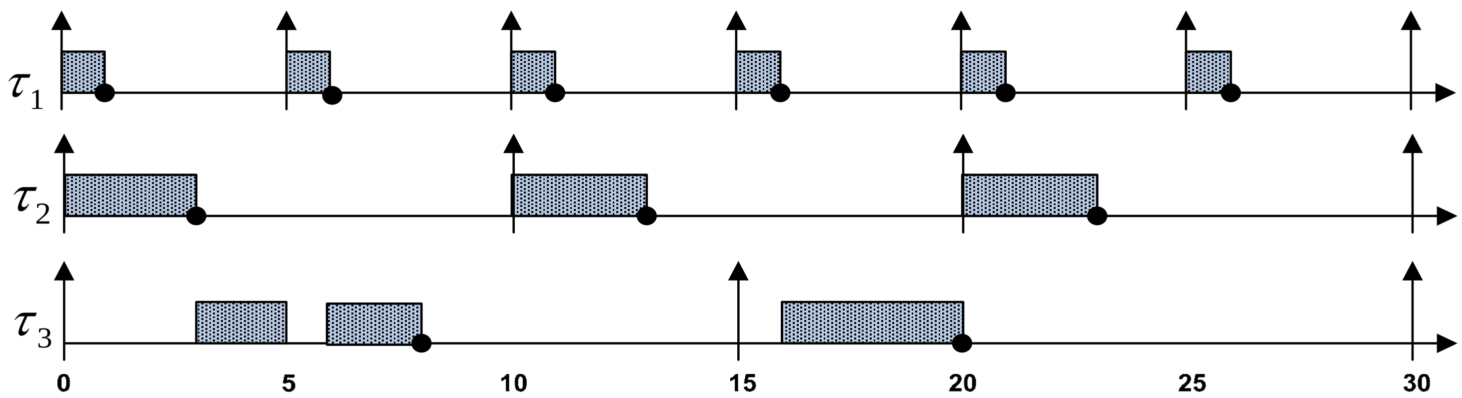
Tightness of analysis (2)

Parallel Interference



- When parallel interference exists, the real worst case network latency is no more than the analysis result.
- When parallel interference exists, finding worst case network latency is NP-hard (the proof details refers the paper).
- Our analysis is safe but pessimistic.

Conclusion

- Real time communication service can be supported by priority based wormhole switching technique.
- The schedulable test is derived by worst case network latency analysis.
- Both direct and indirect interferences are taken into account.
- When parallel interference exists, finding worst case network latency is NP-hard, but our analysis still form an upper bound.

Thank you…
and Question