Chapter 4:
Routing Algorithms
Outline

• Properties impacted by Routing Algorithms
• Taxonomy of Routing Algorithms
• Routing Algorithms for Direct Networks
  – deterministic
  – partially-adaptive
  – fully-adaptive
• Routing in MINs
• Routing in Irregular Networks
Properties impacted by Routing

- Connectivity
- Adaptivity
- Deadlock and Livelock Freedom
- Fault-tolerance
Figure 4.1: A taxonomy for routing protocols
Deterministic Routing

Algorithm: XY-Routing for 2-D Meshes

Inputs: Coordinates of current node \((X_{\text{current}}, Y_{\text{current}})\)
        and destination node \((X_{\text{dest}}, Y_{\text{dest}})\)

Output: Selected output Channel

Procedure:
\[
\begin{align*}
X_{\text{offset}} & := X_{\text{dest}} - X_{\text{current}}; \\
Y_{\text{offset}} & := Y_{\text{dest}} - Y_{\text{current}}; \\
\text{if } X_{\text{offset}} < 0 \text{ then} & \quad \text{Channel} := X-; \\
\text{endif} & \\
\text{if } X_{\text{offset}} > 0 \text{ then} & \quad \text{Channel} := X+; \\
\text{endif} & \\
\text{if } X_{\text{offset}} = 0 \text{ and } Y_{\text{offset}} < 0 \text{ then} & \quad \text{Channel} := Y-; \\
\text{endif} & \\
\text{if } X_{\text{offset}} = 0 \text{ and } Y_{\text{offset}} > 0 \text{ then} & \quad \text{Channel} := Y+; \\
\text{endif} & \\
\text{if } X_{\text{offset}} = 0 \text{ and } Y_{\text{offset}} = 0 \text{ then} & \quad \text{Channel} := \text{Internal}; \\
\text{endif} & 
\end{align*}
\]

Figure 4.3: The XY-routing algorithm for 2-D meshes
X-Y/E-cube Routing

Figure 4.2: Routing example for dimension-order routing on a 2-D mesh
Routing in Ring/Tori

Figure 4.5: Unidirectional rings and their channel dependency graphs
Partially-Adaptive (Planar)

a) Fully-adaptive

b) Planar-adaptive

c) Planar-adaptive

- Current node
- Destination node

Figure 4.7: Allowed paths in fully-adaptive and planar-adaptive routing
Planar-Adaptive

Figure 4.8: Increasing and decreasing networks in plane $A_i$ for planar-adaptive routing
Turn Model

(a) abstract cycles in 2-D mesh
(b) four turns (solid arrows) allowed in XY routing
(c) six turns (solid arrows) allowed in west-first routing

Figure 4.9: An illustration of the turn model in 2-D mesh
West-First Routing

Figure 4.11: Examples of west-first routing in an 8 × 8 2-D mesh.
Fully-Adaptive/Virtual Network

![Virtual Networks](image)

Figure 4.16: Virtual networks for a 2-D mesh
Two kinds of virtual channels (networks)
  - basic
  - additional

Let $R_1$ be a routing sub-function on basic channels
  - connected
  - deadlock-free
  - deterministic or adaptive

A routing function $R$ is fully-adaptive
  - at a node, get routed by additional channels if available
  - if all additional channels are busy, wait on the `basic’ channel(s) according to routing sub-function $R_1$

Minimum number of virtual channels
  - 2 (1 basic and 1 additional) for k-ary n-mesh
  - 3 (2 basic and 1 additional) for k-ary n-cube
Routing in MIN/Self-Routing

Figure 4.30: Paths selected by the tag-based routing algorithm in a 16-node butterfly MIN
Routing in BMINs

(a) FirstDifference$(S,D)=2$ and four shortest paths
(b) FirstDifference$(S,D)=1$ and two shortest paths

Figure 4.31: Paths available in an 8-node bidirectional butterfly MIN
Routing in Irregular Networks

Figure 4.32: (a) An example system with switch-based interconnect and irregular topology; (b) the corresponding graph $G$
Figure 4.33: BFS spanning tree and link direction assignment