Parallel and Distributed Computing
CS3006 (BCS-6C/6D)
Lecture 15

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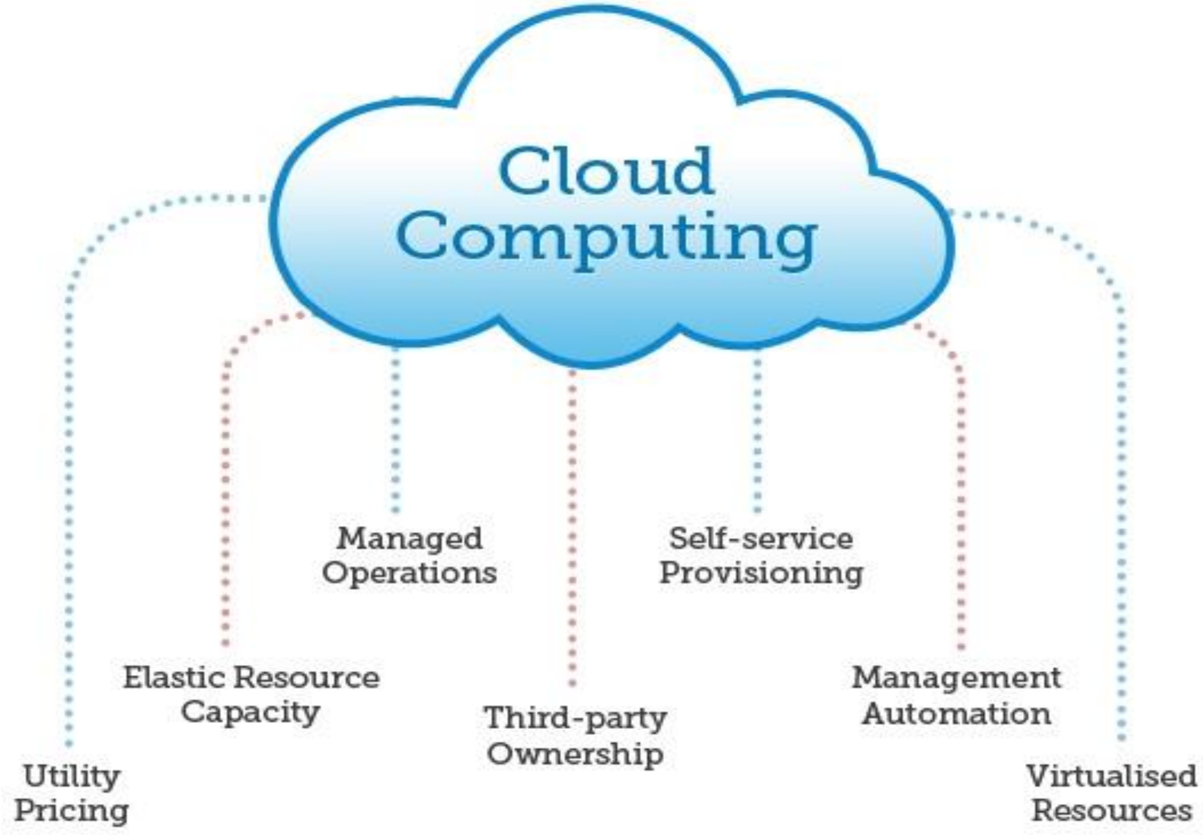
Previous Lecture

- Clusters
  - Types of clusters: Failover, LB, High Performance
  - Challenges in making clusters
- Utility Computing
  - Grid Computing
  - LHC
  - eScience
  - Interplanetary Grid
  - Grid Computing Environment
  - Middleware, Heterogeneity

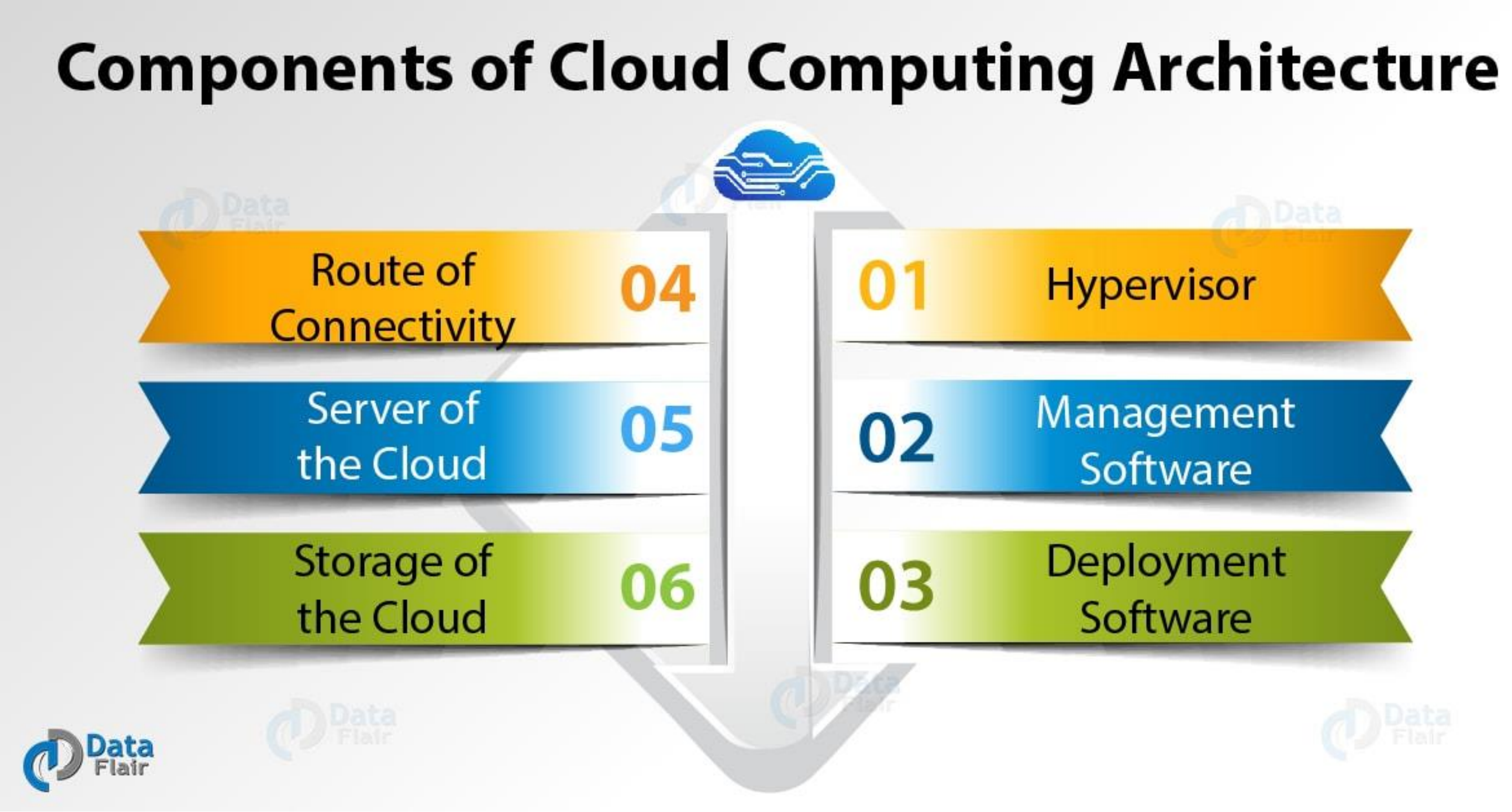
Cloud Computing

- A pool of abstracted, virtualized, dynamically-scalable, managed computing power, storage, platforms, and services that are delivered on demand to external customers over the Internet



Cloud Computing

- Clouds can execute any job that was good for Grids plus
  - More attractive due to platform plus elastic on-demand model
  - Services can be dynamically configured (via virtualization or other approaches) and delivered on demand
  - Massively scalable
  - Can be encapsulated as an abstract entity that delivers different levels of service
  - Illusion of infinite computing resources available on demand, thereby eliminating the need for Cloud Computing users to plan far ahead for provisioning
  - Ability to pay for use of computing resources on a short-term basis as needed (e.g., processors by the hour and storage by the day) and release them as needed


Components of Cloud Computing Architecture
01
Hypervisor
02
Management Software
03
Deployment Software
04
Route of Connectivity
05
Server of the Cloud
06
Storage of the Cloud
Data Flair

Cloud Components

- Hypervisor (*Virtual Machine Monitor)*

  It is a low-level program that acts as a Virtual Machine Manager. It allows to share the single physical instance of cloud resources between several users. The Hypervisor provides a user with a platform which is known as *Virtual Operating Platform*.

- Management Software

  It consists of various plans and the strategies to manage and improve the performance of the cloud. Features include on-time delivery of storage, security, all-time access, compliance auditing, disaster management etc.

- Deployment Software

  This deployment consists of all the mandatory installations and configurations of the cloud *to initiate the working of the SaaS, PaaS, and IaaS*.

Cloud Components

- Cloud Server

  Cloud servers have all the software they need to run and can operate as non-dependent units. It also has the profit because it is incredibly simple and fast to upgrade by adding memory and disk space, further as being more cost-effective.

- Cloud Storage

  It provides access to offsite storage that may be provisioned instantly, it is versatile and could be scaled automatically at runtime and is globally accessible.

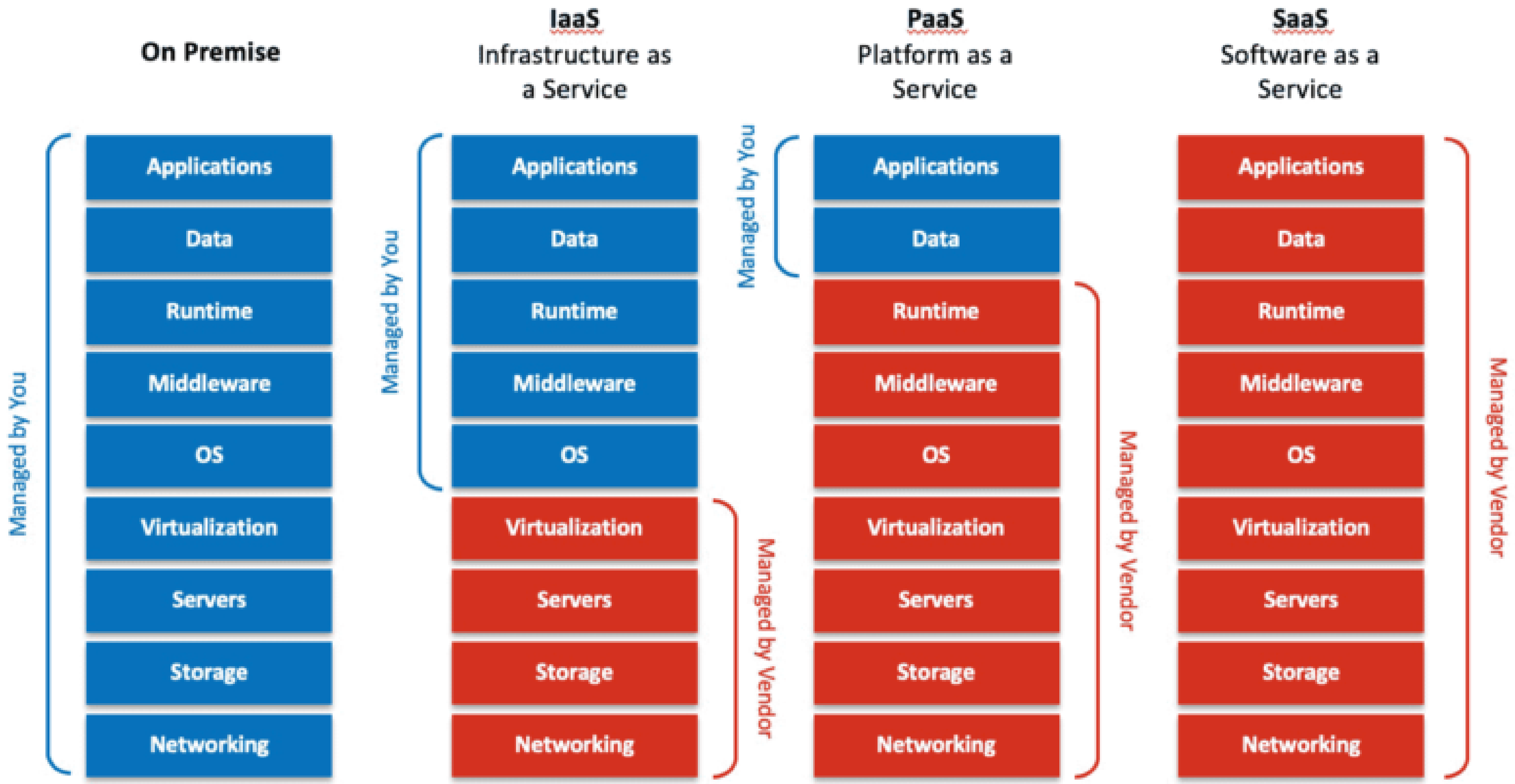
- Route of Connectivity

  The network through which the whole cloud gets connected. There are many cloud servers present which connect with the help of this virtual route. The speed of transfer depends on the network which is the Internet connection.

Cloud Computing Service Model

- Cloud computing offers its benefits through three types of service or delivery models namely
- Infrastructure-as-a-service (IaaS)
  - Hardware software, equipment, can scale up and down
  - Examples: Amazon Elastic Compute Cloud (EC2) and Simple Storage Service (S3)
- Platform-as-a-service (PaaS)
  - High level integrated environment to build, test, and deploy custom apps
  - Example: Google App Engine
- Software-as-a-Service (SaaS)
  - Special purpose software that is remotely accessible
  - Examples: Google Maps, Google Docs, Gmail, Microsoft OneDrive

Cloud Computing Service Model



Types of clouds

- Public cloud
  - the cloud infrastructure is accessible to general public
  - cloud resources are accessible via the internet and the provider is responsible for the management of the shared infrastructure
  - Amazon Web Services EC2
- Private cloud
  - the general public does not have access to the private cloud
  - cloud resources in this model may be located within the client organization premises or offsite
- Community cloud
- Hybrid cloud

Types of clouds

- Community cloud
  - cloud infrastructure is shared by multiple organizations or institutions that have a shared concern or interest
  - both the public and the organizations forming the community cloud have access to the cloud services offered by the community cloud
- Hybrid cloud
  - combines different clouds for example the private and public clouds
  - general public does not have access to the cloud, but the organization uses infrastructure in both the public and private cloud

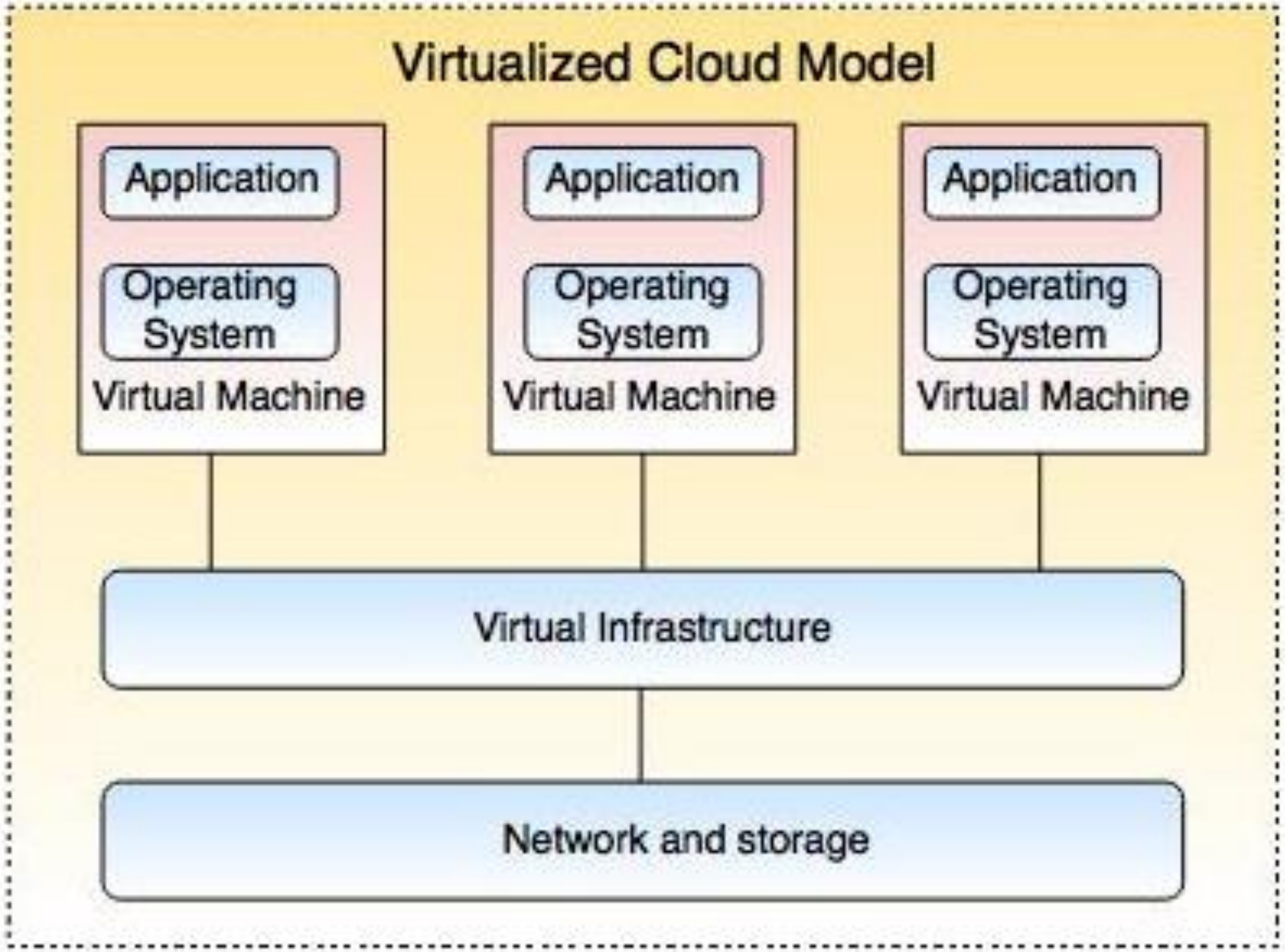
Virtualization

- Virtualization is the partitioning of a single physical server into multiple logical servers.

- Once the physical server is divided, each logical server behaves like a physical server and can run an OS and applications independently.

- Many popular companies like *VMWare* and *Microsoft* provide virtualization services, where instead of using your personal PC for storage and computation, you use their virtual server. They are fast, cost-effective and less time consuming.

Virtualization



Virtualization purposes

- Network Virtualization: It is a method of combining the available resources in a network by splitting up the available bandwidth into channels, each of which is independent from the others and each channel is independent of others and can be assigned to a specific server or device in real time.

- Storage Virtualization: It is the pooling of physical storage from multiple network storage devices into what appears to be a single storage device that is managed from a central console. Storage virtualization is commonly used in storage area networks (SANs).

- Server Virtualization: Server virtualization is the masking of server resources like processors, RAM, operating system etc., from server users. The intention of server virtualization is to increase the resource sharing and reduce the burden and complexity of computation from users.

Cloud vs Grid

- Cloud is a collection of computers usually owned by a single party.
- Cloud computing is a centralized model.
- Cloud computing works more as a service provider for utilizing computer resource.

- A grid is a collection of computers which is owned by multiple parties in multiple locations and connected together so that users can share the combined power of resources.
- Grid computing is a decentralized model, where the computation could occur over many administrative model.
- Grid computing uses the available resource and interconnected computer systems to accomplish a common goal.

Basic Communication Operations

Basic Communication Operations

- Preliminaries
  - Exchanging data is a fundamental requirement for most of the parallel algorithms
  - $\boldsymbol{t_s + mt_w}$ - the simplified communication cost model :-
    - Over distributed memory infrastructure
    - Assuming cut-through routing
  - This chapter is about commonly used basic communication patterns over the different interconnections
    - We shall derive communication costs of these operations on different interconnections.

Basic Communication Operations

- **Assumptions for the Operations**
  - Interconnections support cut-through routing
  - Communication time between any pair of nodes in the network is the same (regardless of the number of intermediate nodes)
  - Links are bi-directional
    - The directly connected nodes can simultaneously send messages of *m words* without any congestion
  - Single-port communication model
    - A node can send on only one of its links at a time
    - A node can receive on only one of its links at a time
  - However, a node can receive a message while sending another message at the same time on the same or a different link.

Basic Communication Operations

- **One-to-All Broadcast**
- **All-to-One Reduction**

Basic Communication Operations
(One-to-All Broadcast and All-to-One Reduction)

- **One-to-All Broadcast**
  - A single process sends identical data to all other processes.
    - Initially one process has data of size *m*.
    - After the broadcast operation, each of the processes have their own copy of size *m*.
- **All-to-One Reduction**
  - Dual of one-to-all broadcast
  - The *m-sized* data from all processes are combined through an associative operator
  - accumulated at a single destination process into one buffer of size *m*

Basic Communication Operations
(One-to-All Broadcast and All-to-One Reduction)

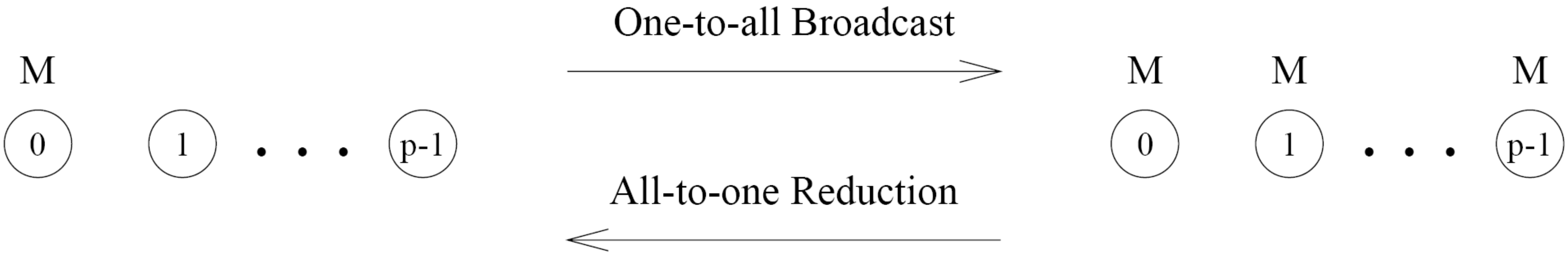


Figure 4.1 One-to-all broadcast and all-to-one reduction.

Basic Communication Operations
(One-to-All Broadcast and All-to-One Reduction)

- **Linear Array or Ring**
  - Naïve solution
    - Sequentially send p - 1 messages from the source to the other p - 1 processes
      - Bottlenecks, and underutilization of communication network
    - Solution?
  - Recursive doubling
    - Source process sends the message to another process
    - In the next communication phase both the processes can simultaneously propagate the message

Basic Communication Operations
(One-to-All Broadcast and All-to-One Reduction)

- **Linear Array or Ring**
  - Recursive Doubling Broadcast

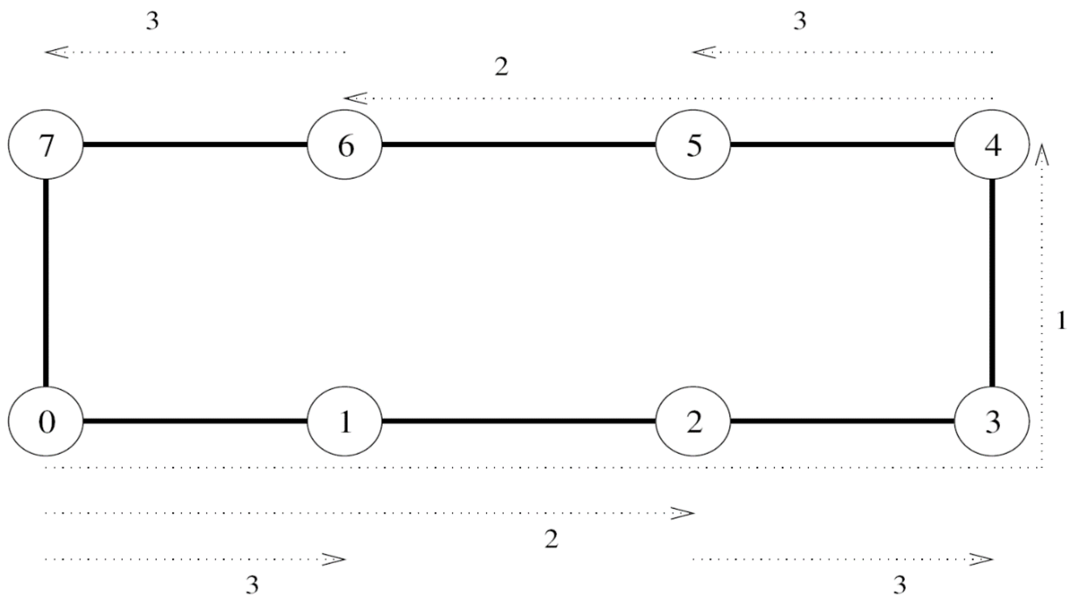


Figure 4.2 One-to-all broadcast on an eight-node ring. Node 0 is the source of the broadcast. Each message transfer step is shown by a numbered, dotted arrow from the source of the message to its destination. The number on an arrow indicates the time step during which the message is transferred.

Basic Communication Operations
(One-to-All Broadcast and All-to-One Reduction)

- **Linear Array or Ring**
  - Recursive Doubling Reduction

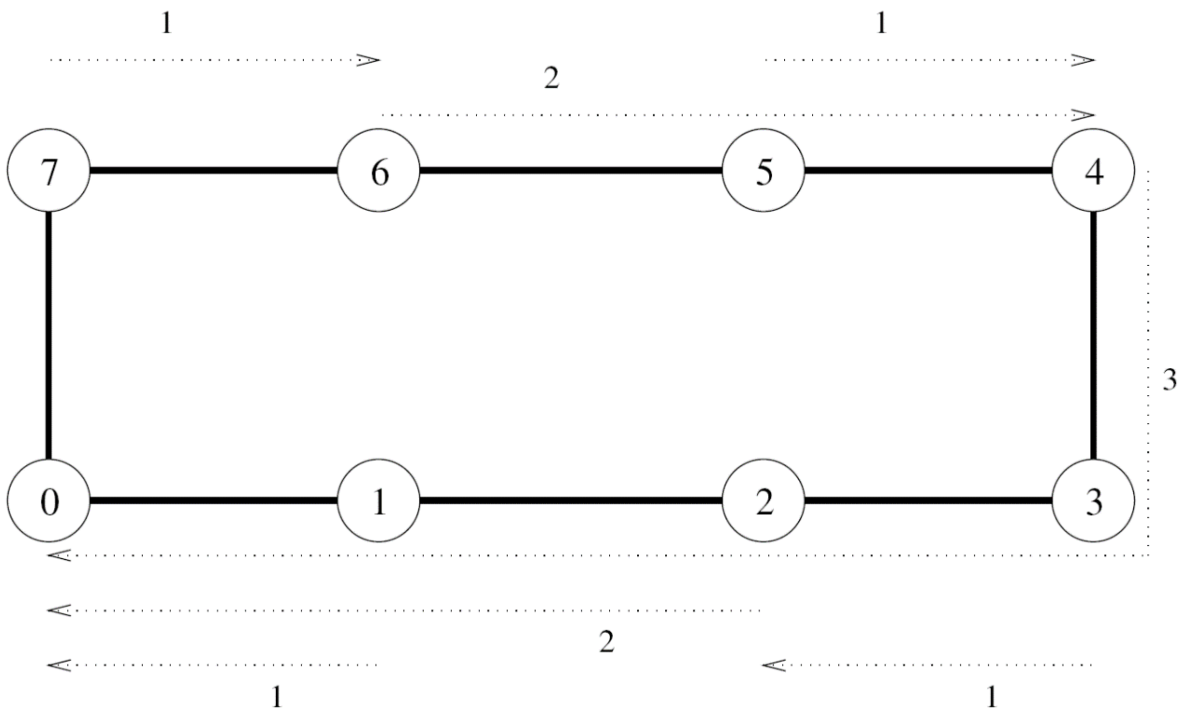


Figure 4.3 Reduction on an eight-node ring with node 0 as the destination of the reduction.

Basic Communication Operations
(One-to-All Broadcast and All-to-One Reduction)

- Matrix-Vector Multiplication (An Application)

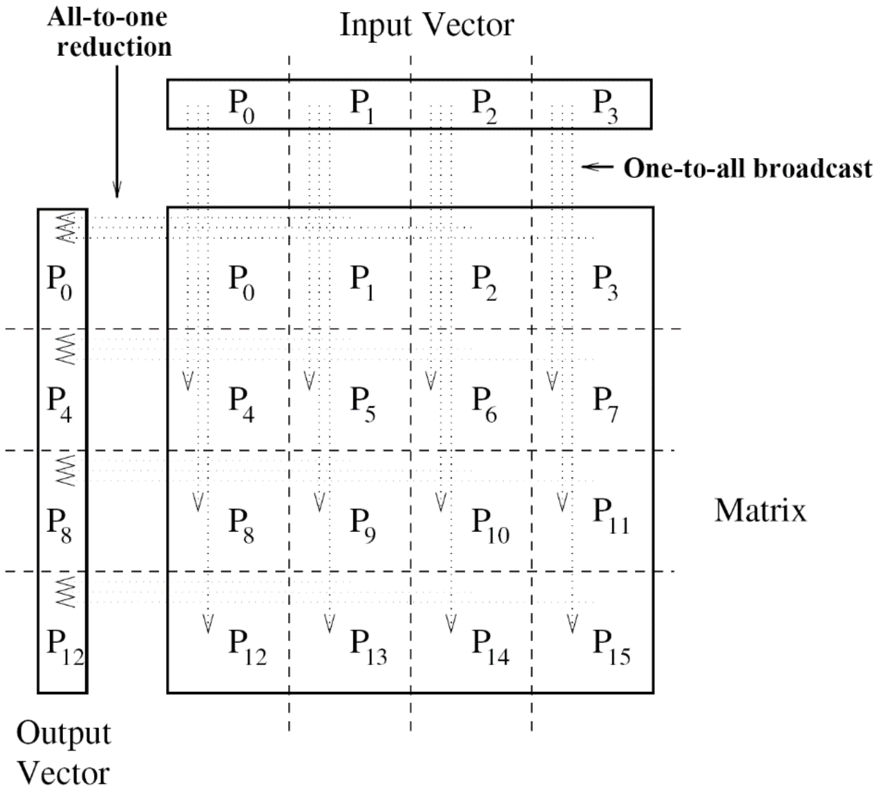


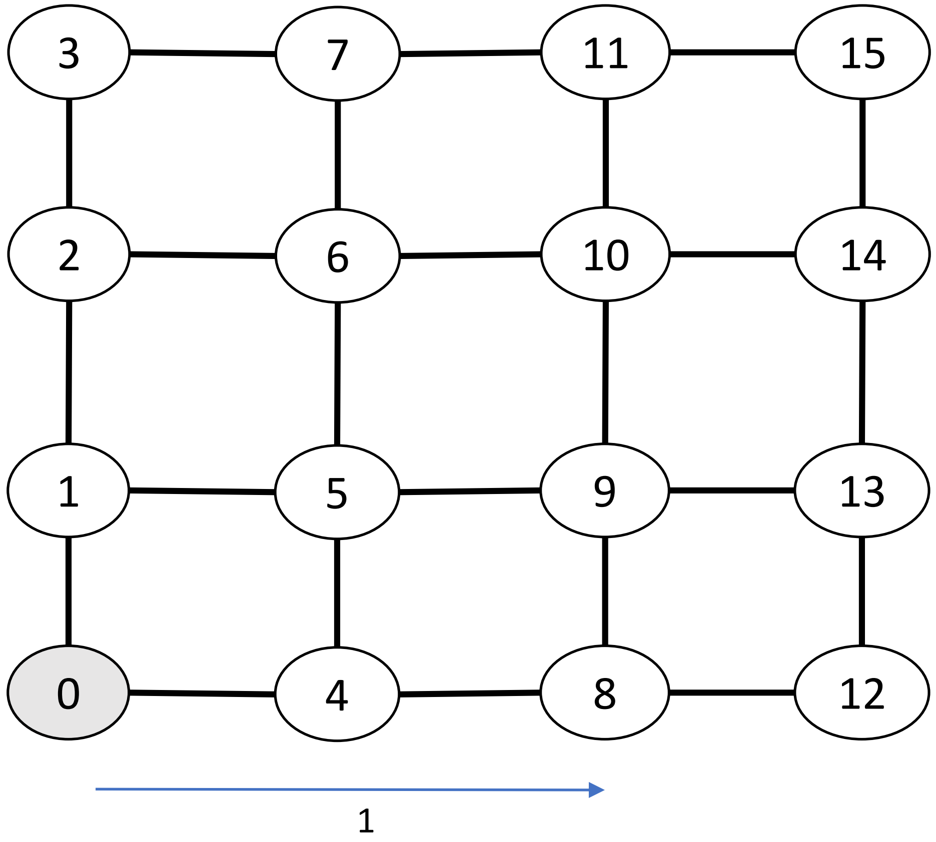
Figure 4.4 One-to-all broadcast and all-to-one reduction in the multiplication of a 4×4 matrix with a 4×1 vector.

Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh**
  - We can regard each row and column of a square mesh of *p* nodes as a linear array of nodes
  - Communication algorithms on the mesh are simple extensions of their linear array counterparts
  - **Broadcast and Reduction**
    - Two step breakdown:
      - The operation is performed along one by treating the row as linear array
      - Then all the columns are treated similarly

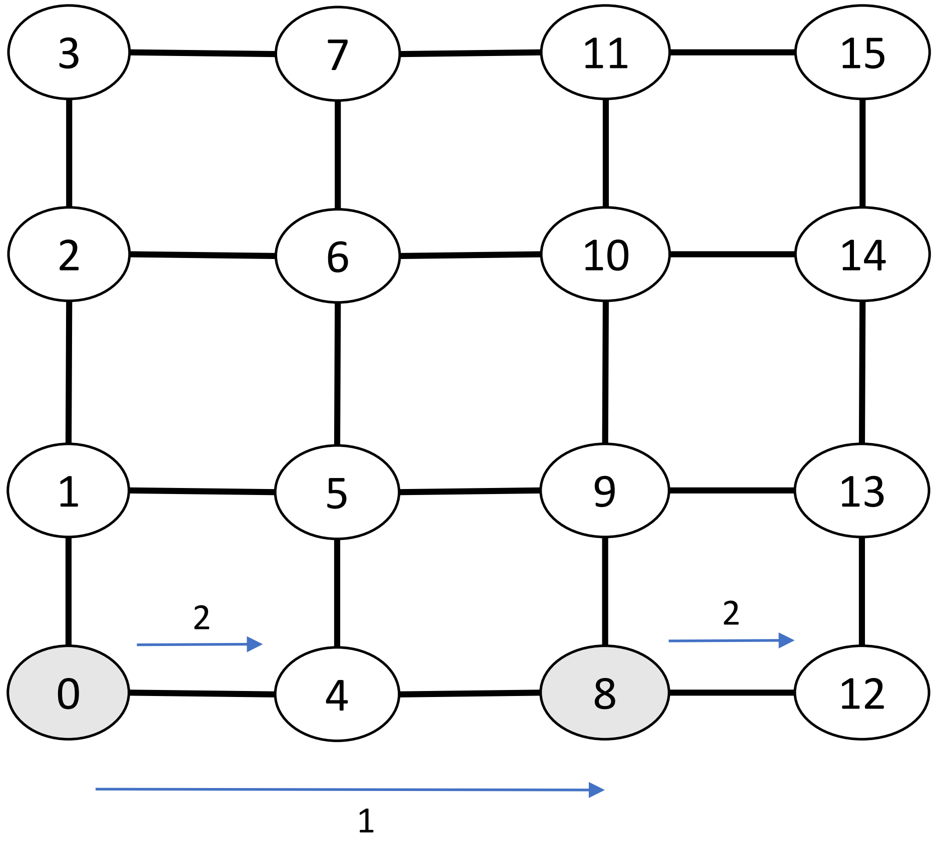
Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**



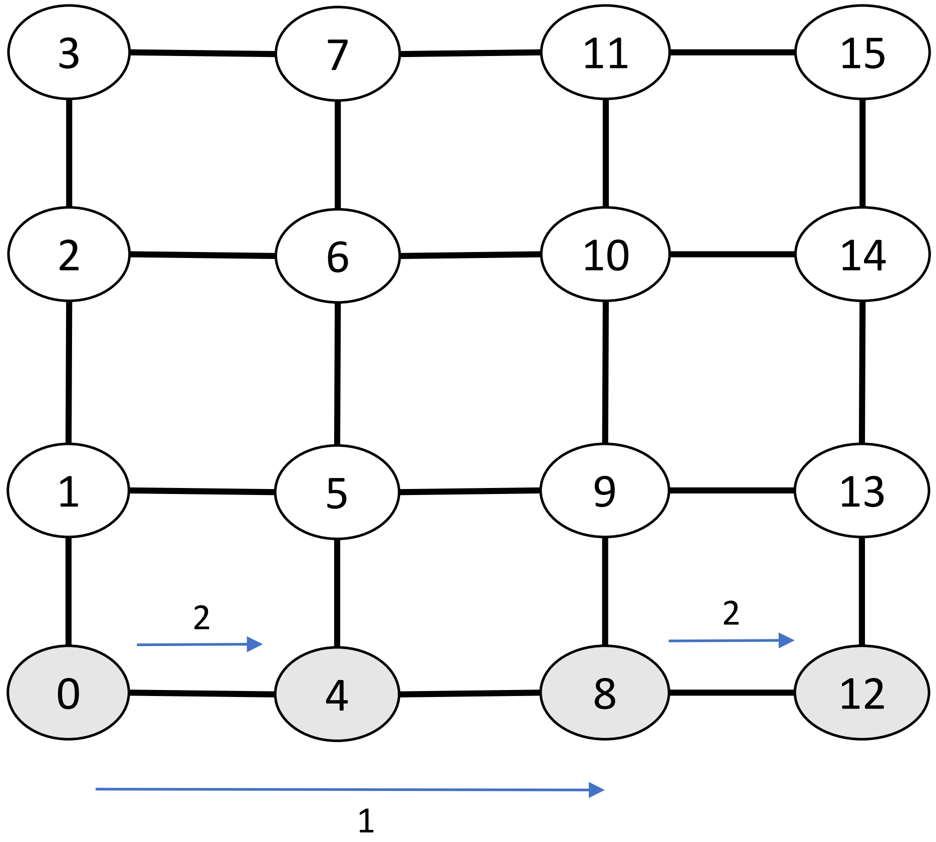
Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**



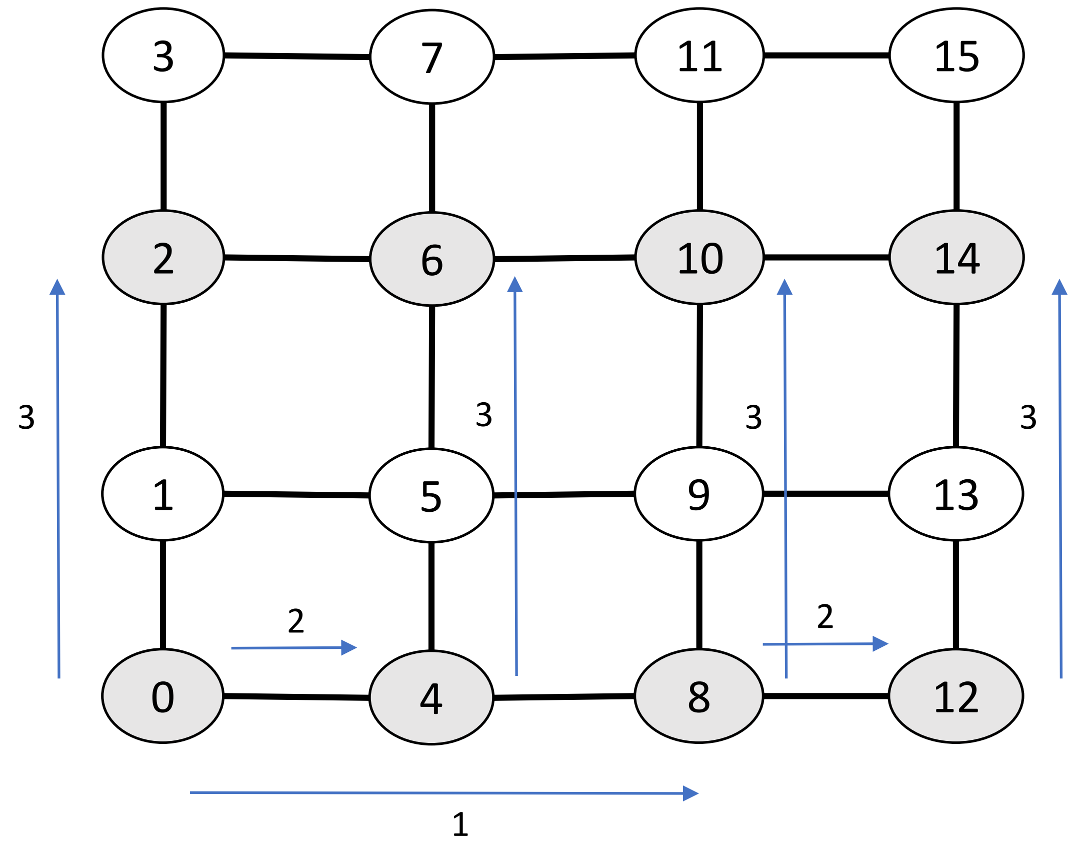
Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**



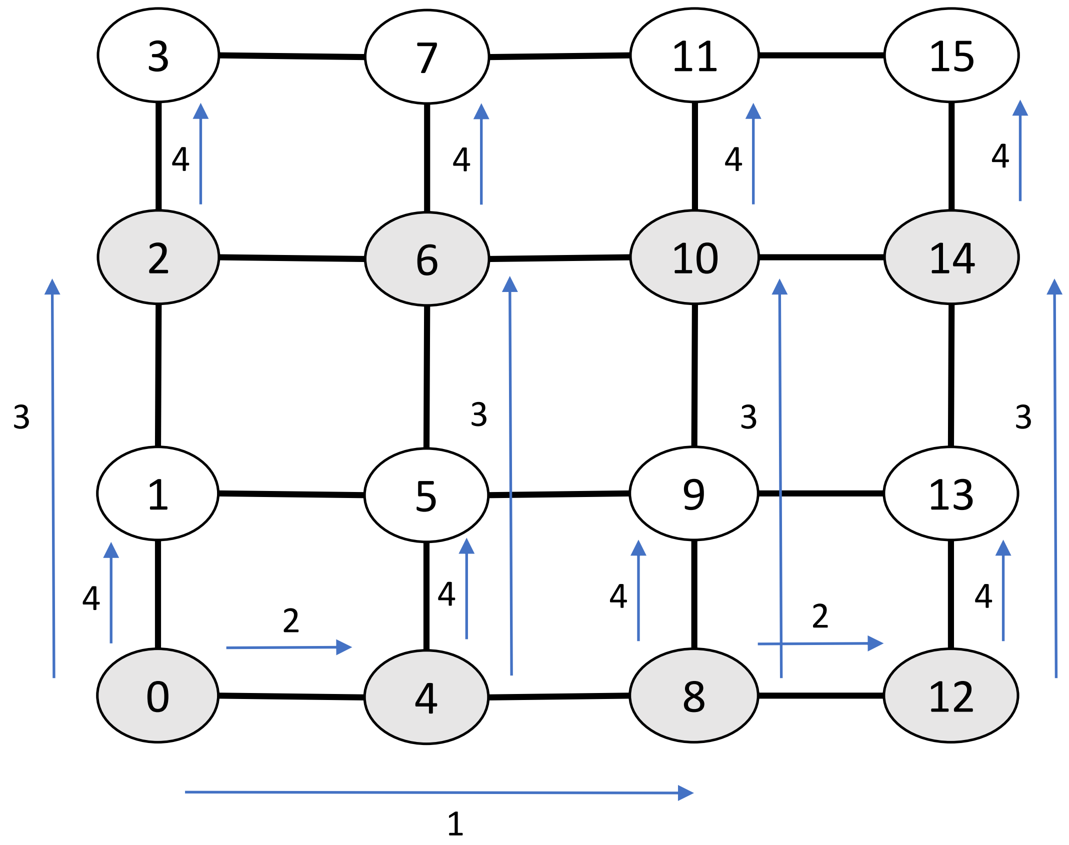
Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**



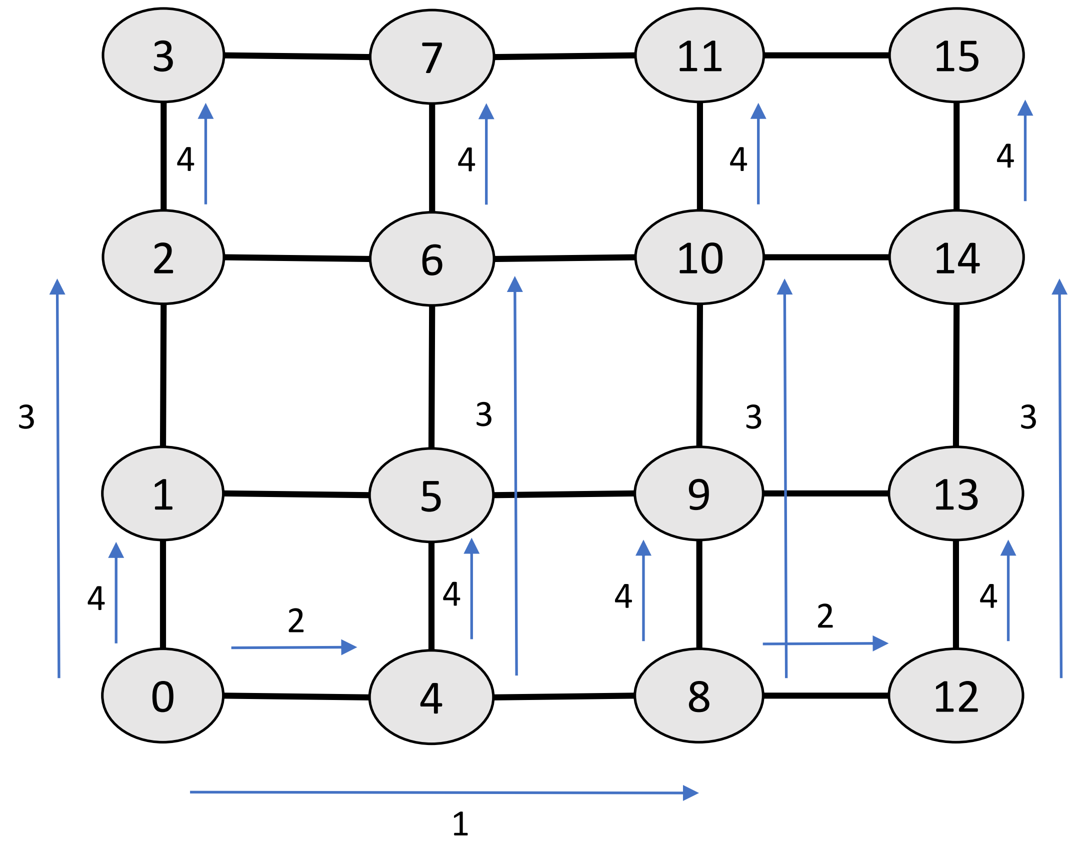
Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**



Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**



Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- **Mesh (broadcast and reduction)**

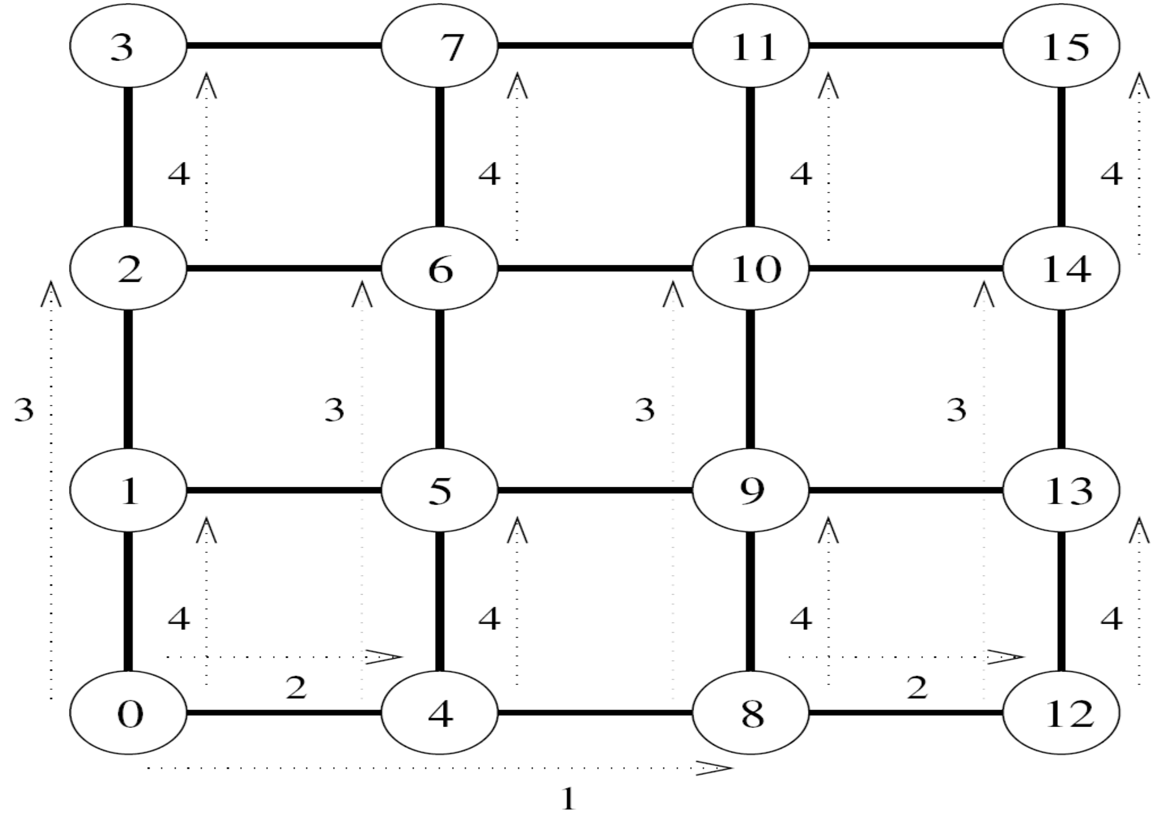


Figure 4.5 One-to-all broadcast on a 16-node mesh.

Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

- Balanced Binary Tree

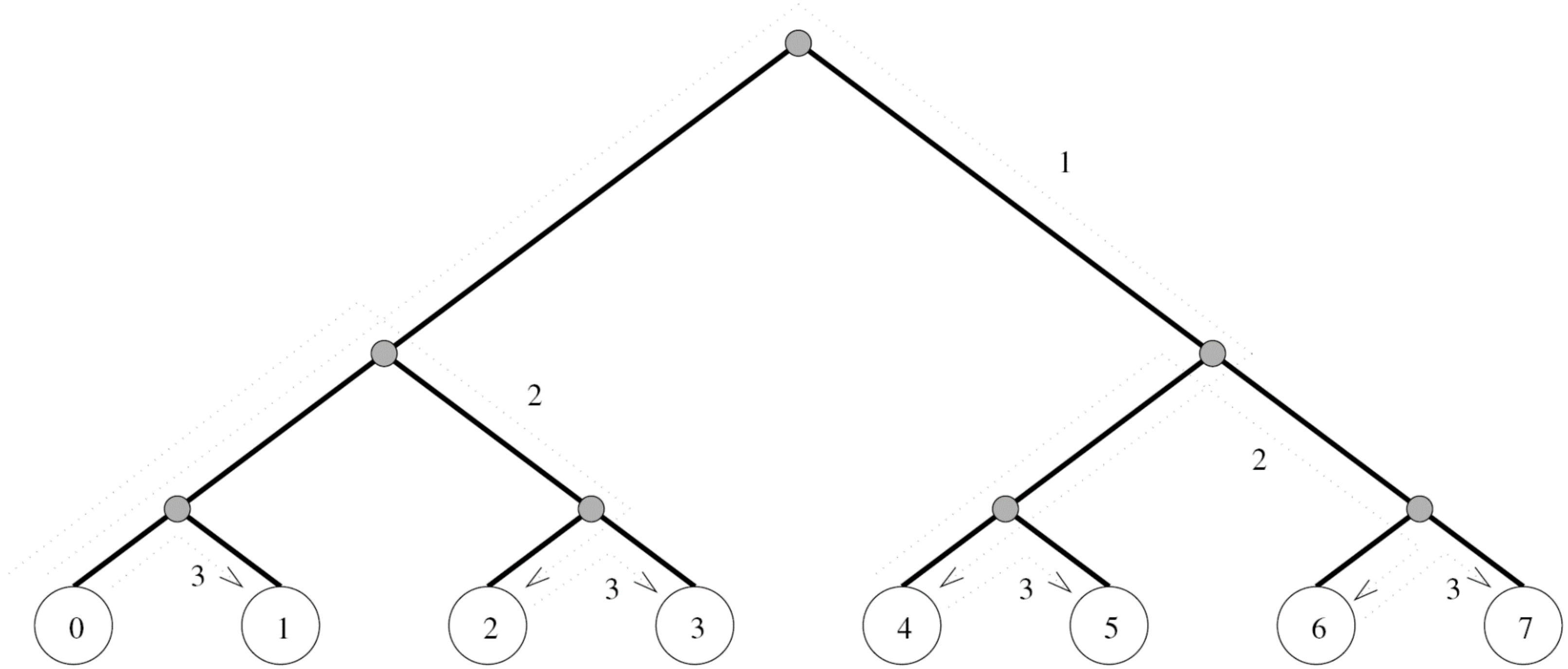


Figure 4.7 One-to-all broadcast on an eight-node tree.

Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

Hypercube

- Broadcast
  - Source node first sends data to one node in the highest dimension
  - The communication successively proceeds along lower dimensions in the subsequent steps
  - The algorithm is the same as used for linear array
    - But here, changing order of dimension does not congest the network

Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

Hypercube

- Broadcast

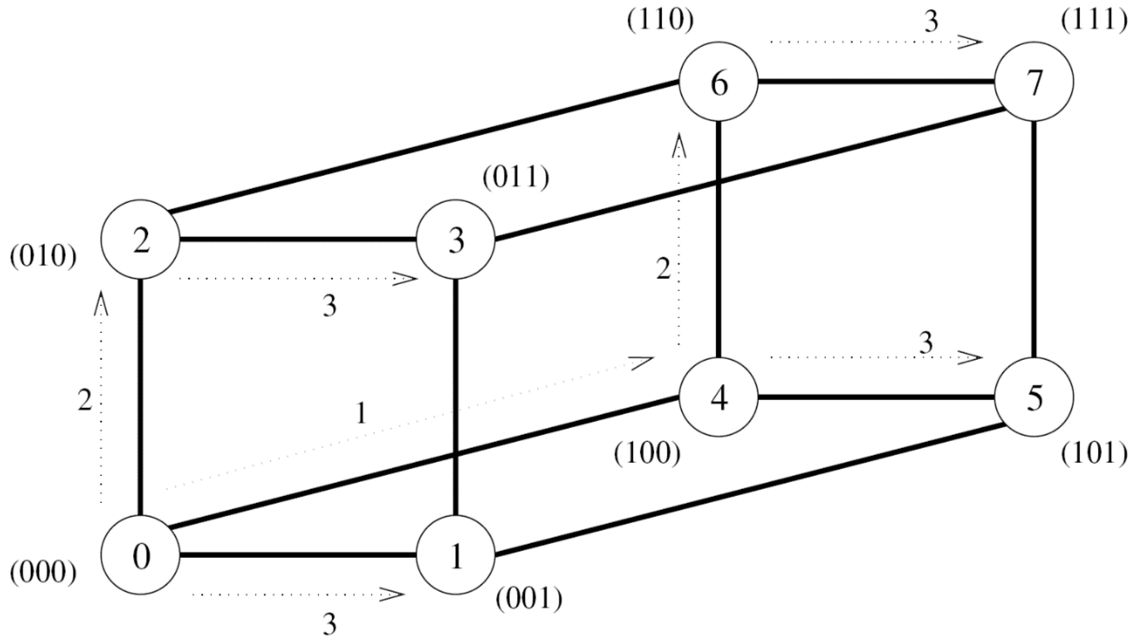


Figure 4.6 One-to-all broadcast on a three-dimensional hypercube. The binary representations of node labels are shown in parentheses.

Basic Communication Operations (One-to-All Broadcast and All-to-One Reduction)

Please read the book (chapter 4)

```
procedure ONE_TO_ALL_BC(d, my_id, X)
begin
    mask := 2^d - 1;                          /* Set all d bits of mask to 1 */
    for i := d - 1 downto 0 do                /* Outer loop */
        mask := mask XOR 2^i;                 /* Set bit i of mask to 0 */
        if (my_id AND mask) = 0 then          /* If lower i bits of my_id are 0 */
            if (my_id AND 2^i) = 0 then
                msg_destination := my_id XOR 2^i;
                send X to msg_destination;
            else
                msg_source := my_id XOR 2^i;
                receive X from msg_source;
            endelse;
        endif;
    endfor;
end ONE_TO_ALL_BC
```

Algorithm 4.1 One-to-all broadcast of a message X from node 0 of a d-dimensional p-node hypercube ($d = \log p$). AND and XOR are bitwise logical-and and exclusive-or operations, respectively.

References

1. Slides from Dr. Rana Asif Rehman & Dr. Haroon Mahmood
2. Kumar, V., Grama, A., Gupta, A., & Karypis, G. (1994). *Introduction to parallel computing* (Vol. 110). Redwood City, CA: Benjamin/Cummings.
3. Quinn, M. J. Parallel Programming in C with MPI and OpenMP,(2003).