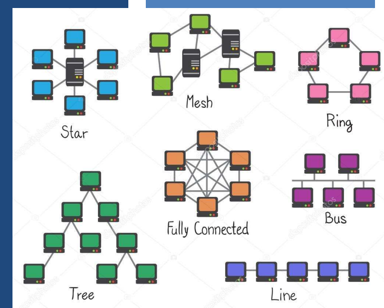
TCSS 558: APPLIED DISTRIBUTED COMPUTING

Communication



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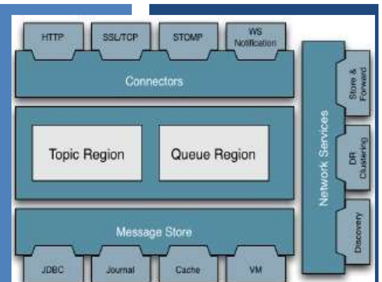
OBJECTIVES

- Assignment #1 Questions
- Assignment #2
- Ch. 4 – Communications
  - Message-oriented communication:
    - Zeromq, MPI,
    - Message Queueing Systems
    - Multicast communication

CHAPTER 4

- 4.1 Foundations
  - Protocols
  - Types of communication
- 4.2 Remote procedure call
- 4.3 Message-oriented communication
  - Socket communication
  - Messaging libraries
  - Message-Passing Interface (MPI)
  - Message-queueing systems
  - Examples
- 4.4 Multicast communication
  - Flooding-based multicasting
  - Gossip-based data dissemination



Apache ActiveMQ

CH. 4.3: MESSAGE-ORIENTED COMMUNICATION

MESSAGE ORIENTED COMMUNICATION

- RPC assumes that the ***client*** and ***server*** are running ***at the same time… (temporally coupled)***
- RPC communication is typically ***synchronous***
- When client and server are not running at the same time
- Or when communications should not be **blocked…**
- **This is a use case for message-oriented communication**
  - Synchronous vs. asynchronous
  - Messaging systems
  - Message-queueing systems

SOCKETS

- Communication end point
- Applications can read / write data to
- Analogous to file streams for I/O, but ***network streams***

Operation	Description
socket	Create a new communication end point
bind	Attach local address to socket (IP / port)
listen	Tell OS what max # of pending connection requests should be
accept	Block caller until a connection request arrives
connect	Actively attempt to establish a connection
send	Send some data over the connection
receive	Receive some data over the connection
close	Release the connection

SOCKETS - 2

- Servers execute 1st - 4 operations (socket, bind, listen, accept)
- Methods refer to C API functions
- Mappings across different libraries will vary (*e.g. Java*)

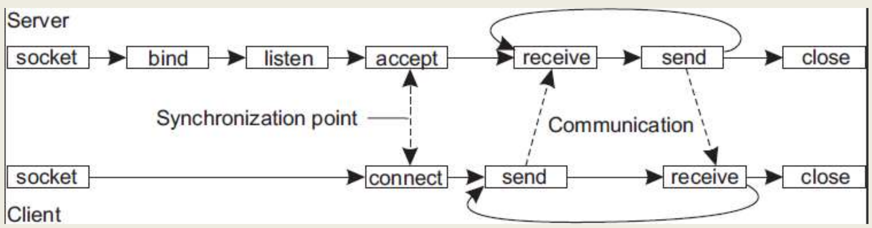
Operation	Description
socket	Create a new communication end point
bind	Attach local address to socket (IP / port)
listen	Tell OS what max # of pending connection requests should be
accept	Block caller until a connection request arrives
connect	Actively attempt to establish a connection
send	Send some data over the connection
receive	Receive some data over the connection
close	Release the connection

SERVER SOCKET OPERATIONS

- **Socket**: creates new communication end point
- **Bind**: associated IP and port with end point
- **Listen**: for connection-oriented communication, non-blocking call reserves buffers for specified number of pending connection requests server is willing to accept
- **Accept**: blocks until connection request arrives
  - Upon arrival, new socket is created matching original
  - Server spawns thread, or forks process to service incoming request
  - Server continues to wait for new connections on original socket

CLIENT SOCKET OPERATIONS

- **Socket**: Creates socket client uses for communication
- **Connect**: Server transport-level address provided, client blocks until connection established
- **Send**: Supports sending data (to: server/client)
- **Receive**: Supports receiving data (from: server/client)
- **Close**: Closes communication channel
  - Analogous to closing a file stream

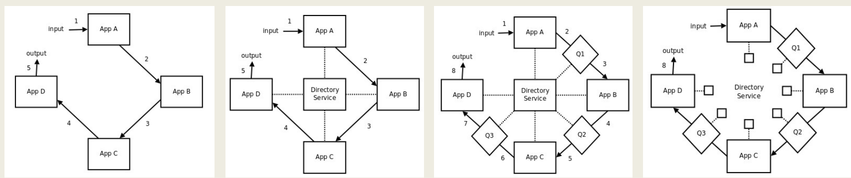


SOCKET COMMUNICATION

- Sockets provide primitives for implementing your own TCP/UDP communication protocols
- Directly using sockets for transient (non-persisted) messaging is very basic, can be brittle
  - Easy to make mistakes…
- Any extra communication facilities must be implemented by the application developer
- More advanced approaches are desirable
  - E.g. frameworks with support common desirable functionality

ZEROMQ

- (0MQ) High performance intelligent socket library
- *zero broker, zero latency, zero admin, zero cost, zero waste*
- Provides a message queue
- ***Builds upon*** functionality of traditional sockets
- Implementation in C++
  - 30+ language bindings provided
- Enables support for various messaging patterns
- Can support brokered (centralized) and broker-less topologies



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ZEROMQ – 2

- ZeroMQ is TCP-connection-oriented communication
- Provides socket-like primitives with more functionality
  - Basic socket operations ***abstracted*** away
  - Supports many-to-one, one-to-one, and one-to-many connections
  - ***Multicast*** connections (one-to-many – single server socket simultaneously "connects" to multiple clients)
- Asynchronous messaging
- Supports pairing sockets to support communication patterns

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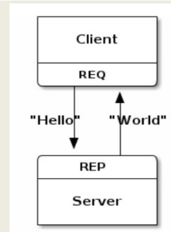
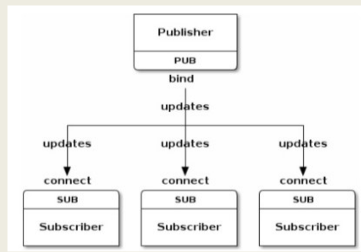
ZEROMQ - PATTERNS

- **Request-reply pattern**
  - Traditional client-server communication (e.g. RPC)
  - Client: request socket (REQ)
  - Server: reply socket (REP)



- **Publish-subscribe pattern**
  - Clients **subscribe** to messages **published** by servers
  - As in event-based coordination (Ch. 1)
  - Supports multicasting messages from server to multiple
  - Client: subscribe socket (SUB)
  - Server: publish socket (PUB)



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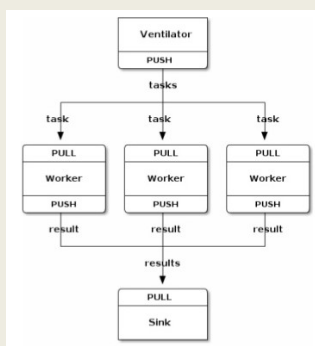
ZEROMQ – PATTERNS - 2

- **Pipeline pattern (FIFO-queue)**
  - Analogous to a producer/consumer bounded buffer
  - Producing processes generate results, push to pipe
  - Consuming processes consume results, pull from pipe
  - Producers: push socket (PUSH socket)
  - Consumers: pull socket (PULL socket)
  - Push- distributes messages to all pull clients evenly
  - Consumers pull results from pipe and push results downstream



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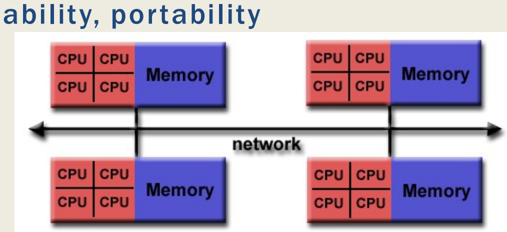
QUEUEING ALTERNATIVES

- Cloud services
  - Amazon Simple Queueing Service (SQS)
  - Azure service bus
- Open source frameworks
  - Nanomsg
  - ZeroMQ

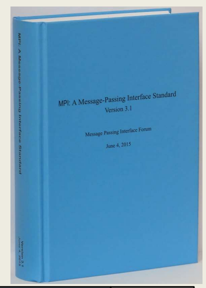
MESSAGE PASSING INTERFACE (MPI)

- MPI introduced – version 1.0 March 1994
- Message passing API for parallel programming: *supercomputers*
- Communication protocol for parallel programming for: Supercomputers, High Performance Computing (HPC) clusters
- Point-to-point and collective communication
- Goals: high performance, scalability, portability
- Most implementations in C, C++, Fortran



MOTIVATIONS FOR MPI

- Motivation: sockets insufficient for interprocess communication on large scale HPC compute clusters and super computers
  - Sockets at the wrong level of abstraction
  - Sockets designed to communicate over the network using general purpose TCP/IP stacks
  - Not designed for proprietary protocols
  - Not designed for high-speed interconnection networks used by supercomputers, HPC-clusters, etc.
  - Better buffering and synchronization needed



MOTIVATIONS FOR MPI - 2

- Supercomputers had proprietary communication libraries
  - Offer a wealth of efficient communication operations
- All libraries mutually incompatible
- Led to significant portability problems developing parallel code that could migrate across supercomputers
- Led to development of MPI
  - To support transient (non-persistent) communication for parallel programming

MPI FUNCTIONS / DATATYPES

- Very large library, v1.0 (1994) 128 functions
- Version 3 (2015) 440+
- MPI data types:
- Provide common mappings

MPI datatype	C datatype
MPI_CHAR	signed char
MPI_SHORT	signed short int
MPI_INT	signed int
MPI_LONG	signed long int
MPI_UNSIGNED_CHAR	unsigned char
MPI_UNSIGNED_SHORT	unsigned short int
MPI_UNSIGNED	unsigned int
MPI_UNSIGNED_LONG	unsigned long int
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_BYTE	
MPI_PACKED	

MPI_ABORT	MPI_ADDRESS	MPI_ALLGATHER	MPI_ALLGATHERV
MPI_ALLREDUCE	MPI_ALLTOALL	MPI_ALLTOALLV	MPI_ATTR_DELETE
MPI_ATTR_GET	MPI_ATTR_PUT	MPI_BARRIER	MPI_BCAST
MPI_BSEND	MPI_BSEND_INIT	MPI_BUFFER_ATTACH	MPI_BUFFER_DETACH
MPI_CANCEL	MPI_CARTDIM_GET	MPI_CART_COORDS	MPI_CART_CREATE
MPI_CART_GET	MPI_CART_MAP	MPI_CART_RANK	MPI_CART_SHIFT
MPI_CART_SUB	MPI_COMM_COMPARE	MPI_COMM_CREATE	MPI_COMM_DUP
MPI_COMM_FREE	MPI_COMM_GROUP	MPI_COMM_RANK	MPI_COMM_REMOTE_GROUP
MPI_COMM_REMOTE_SIZE	MPI_COMM_SIZE	MPI_COMM_SPLIT	MPI_COMM_TEST_INTER
MPI_DIMS_CREATE	MPI_ERRHANDLER_CREATE	MPI_ERRHANDLER_FREE	MPI_ERRHANDLER_GET
MPI_ERRHANDLER_SET	MPI_ERROR_CLASS	MPI_ERROR_STRING	MPI_FINALIZE
MPI_GATHER	MPI_GATHERV	MPI_GET_COUNT	MPI_GET_ELEMENTS
MPI_GET_PROCESSOR_NAME	MPI_GRAPHDIMS_GET	MPI_GRAPH_CREATE	MPI_GRAPH_GET
MPI_GRAPH_MAP	MPI_GRAPH_NEIGHBORS	MPI_GRAPH_NEIGHBORS_COUNT	MPI_GROUP_COMPARE
MPI_GROUP_DIFFERENCE	MPI_GROUP_EXCL	MPI_GROUP_FREE	MPI_GROUP_INCL
MPI_GROUP_INTERSECTION	MPI_GROUP_RANGE_EXCL	MPI_GROUP_RANGE_INCL	MPI_GROUP_RANK
MPI_GROUP_SIZE	MPI_GROUP_TRANSLATE_RANKS	MPI_GROUP_UNION	MPI_IBSEND
MPI_INIT	MPI_INITIALIZED	MPI_INTERCOMM_CREATE	MPI_INTERCOMM_MERGE
MPI_IPROBE	MPI_IRECV	MPI_IRSEND	MPI_ISEND
MPI_ISSEND	MPI_KEYVAL_CREATE	MPI_KEYVAL_FREE	MPI_OP_CREATE
MPI_OP_FREE	MPI_PACK	MPI_PACK_SIZE	MPI_PCONTROL
MPI_PROBE	MPI_RECV	MPI_RECV_INIT	MPI_REDUCE
MPI_REDUCE_SCATTER	MPI_REQUEST_FREE	MPI_RSEND	MPI_RSEND_INIT
MPI_SCAN	MPI_SCATTER	MPI_SCATTERV	MPI_SEND
MPI_SENDRECV	MPI_SENDRECV_REPLACE	MPI_SEND_INIT	MPI_SSEND
MPI_SSEND_INIT	MPI_START	MPI_STARTALL	MPI_TEST
MPI_TESTALL	MPI_TESTANY	MPI_TESTSOME	MPI_TEST_CANCELLED
MPI_TOPO_TEST	MPI_TYPE_COMMIT	MPI_TYPE_CONTIGUOUS	MPI_TYPE_EXTENT
MPI_TYPE_FREE	MPI_TYPE_HINDEXED	MPI_TYPE_HVECTOR	MPI_TYPE_INDEXED
MPI_TYPE_LB	MPI_TYPE_SIZE	MPI_TYPE_STRUCT	MPI_TYPE_UB
MPI_TYPE_VECTOR	MPI_UNPACK	MPI_WAIT	MPI_WAITALL
MPI_WAITANY	MPI_WAITSOME	MPI_WTICK	MPI_WTIME

COMMON MPI FUNCTIONS

- MPI - no recovery for process crashes, network partitions
- Communication among grouped processes: `(groupID, processID)`
- IDs used to route messages in place of IP addresses

Operation	Description
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send message, wait until copied to local/remote buffer
MPI_ssend	Send message, wat until transmission starts
MPI_sendrecv	Send message, wait for reply
MPI_isend	Pass reference to outgoing message and continue
MPI_issend	Pass reference to outgoing messages, wait until receipt start
MPI_recv	Receive a message, block if there is none
MPI_irecv	Check for incoming message, **do not block!**

MESSAGE-ORIENTED-MIDDLEWARE

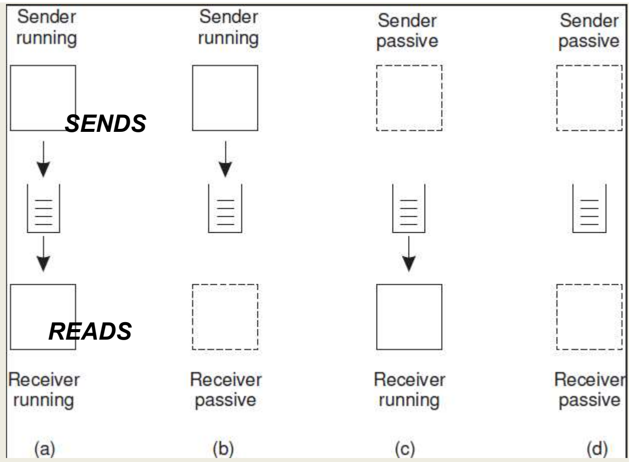
- **Message-queueing systems**
  - Provide extensive support for ***persistent*** asynchronous communication
  - In contrast to transient systems
  - Temporally decoupled: messages are eventually delivered to recipient queues
- Message transfers may take minutes vs. sec or ms
- Each application has its own private queue to which other applications can send messages

MESSAGE QUEUEING SYSTEMS: USE CASES

- Enables communication between applications, or sets of processes
  - User applications
  - App-to-database
  - To support distributed real-time computations
- Use cases
  - Batch processing, Email, workflow, groupware, routing subqueries

MESSAGE QUEUEING SYSTEMS

- Scenarios:
  (a) Sender/receiver both running
  (b) Sender running, receiver offline
  (c) Sender offline, receiver running
  (d) Sender/receiver both offline



- Queue persists msgs, and attempts to send them but no one may be available to receive them…

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MESSAGE QUEUEING SYSTEMS - 2

- Key: Truly persistent messaging
- Message queueing systems can persist messages for awhile and senders and receivers can be offline
- Messages
- Contain *any* data, may have size limit
- Are properly addressed, to a destination queue
- Basic Inteface
- PUT: called by sender to append msg to specified queue
- GET: blocking call to remove oldest msg from specified queue
  - Blocked if queue is empty
- POLL: Non-blocking, gets msg from specified queue

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MESSAGE QUEUEING SYSTEMS ARCHITECTURE

- **Basic interface cont'd**
- NOTIFY: install a callback function, for when msg is placed into a queue. Notifies receivers
- **Queue managers**: manage individual message queues as a separate process/library
- Applications get/put messages only from *local* queues
- Queue manager and apps share local network
- **ISSUES:**
- How should we reference the destination queue?
- How should names be resolved (looked-up)?
  - Contact address (host, port) pairs
  - Local look-up tables can be stored at each queue manager

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MESSAGE QUEUEING SYSTEMS ARCHITECTURE - 2

- **ISSUES**:
- How do we route traffic between queue managers?
  - How are name-to-address mappings efficiently kept?
  - Each queue manager should be known to all others
- **Message brokers**
- Handle message conversion among different users/formats
- Addresses cases when senders and receivers don't speak the same protocol (language)
- Need arises for message protocol converters
  - "Reformatter" of messages
- Act as application-level gateway

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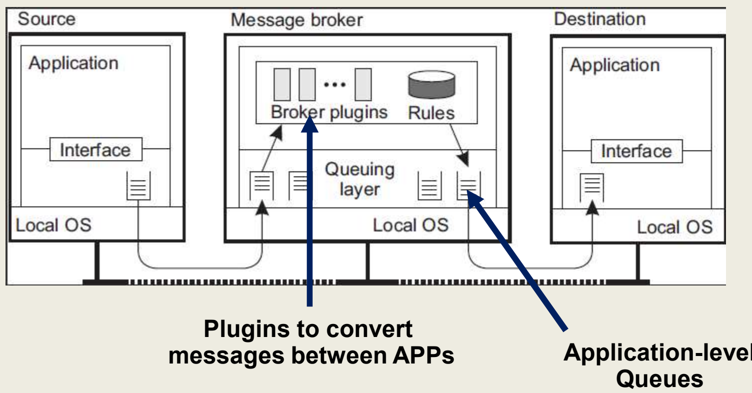
MESSAGE BROKER ORGANIZATION



AMQP PROTOCOL

- Message-queueing systems initially developed to enable legacy applications to interoperate
- Decouple inter-application communication to "open" messaging-middleware
- Many are proprietary solutions, ***so not very open***
- e.g. Microsoft Message Queueing service, Windows NT 1997
- Advanced message queueing protocol (AMQP), 2006
- Address openness/interoperability of proprietary solutions
- Open wire protocol for messaging with powerful routing capabilities
- Help *abstract* messaging and application interoperability by means of a generic open protocol
- Suffer from incompatibility among protocol versions
- pre-1.0, 1.0+

AMQP - 2

- Consists of: Applications, Queue managers, Queues
- **Connections:** set up to a queue manager, TCP, with potentially many channels, stable, reused by many channels, long-lived
- **Channels:** support short-lived one-way communication
- **Sessions:** bi-directional communication across two channels
- **Link:** provide fine-grained flow-control of message transfer/status between applications and queue manager

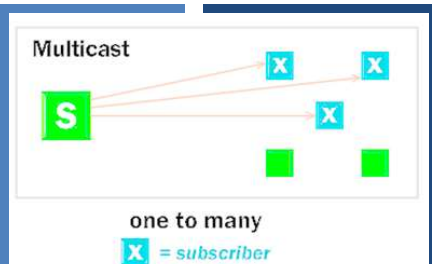
AMQP MESSAGING

- AMQP nodes: producer, consumer, queue
- Producer/consumer: represent regular applications
- Queues: store/forward messages

- Persistent messaging:
- **Messages** can be marked ***durable***
- These messages can only be delivered by nodes able to recover in case of failure
- Non-failure resistant nodes must reject durable messages
- **Source/target** nodes can be marked ***durable***
- Track what is durable (node state, node+msgs)

MESSAGE-ORIENTED-MIDDLEWARE EXAMPLES:

- **Some examples:**
- RabbitMQ, Apache QPid
  - Implement Advanced Message Queueing Protocol (AMQP)
- Apache Kafka
  - **Dumb broker** (message store), similar to a distributed log file
  - **Smart consumers** – intelligence pushed off to the clients
  - Stores stream of records in categories called topics
  - Supports voluminous data, many consumers, with minimal O/H
  - Kafka **does not track** which messages were read by each consumer
  - Messages are removed after timeout
  - Clients must track their own consumption (*Kafka doesn't help*)
  - Messages have key, value, timestamp
  - Supports high volume pub/sub messaging and streams



Apache ActiveMQ

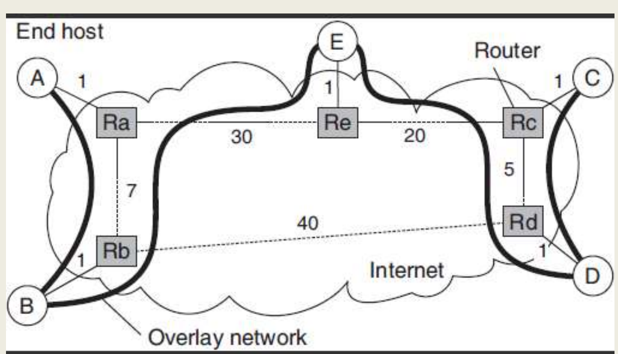
CH. 4.4: MULTICAST COMMUNICATION

MULTICAST COMMUNICATION

- Sending data to multiple receivers
- Many ***failed*** proposals for network-level / transport-level protocols to support multicast communication
- **Problem:** How to set up communication paths for information dissemination?
- **Solutions:** require huge management effort, human invention
- Focus shifted more recently to **peer-to-peer** networks
  - Structured overlay networks can be setup easily and provide efficient communication paths
  - Application-level multicasting techniques more successful
  - Gossip-based dissemination: unstructured p2p networks

NETWORK STRUCTURE

- Overlay network
  - Virtual network implemented on top of an actual physical network
- Underlying network
  - The actual physical network that implements the overlay

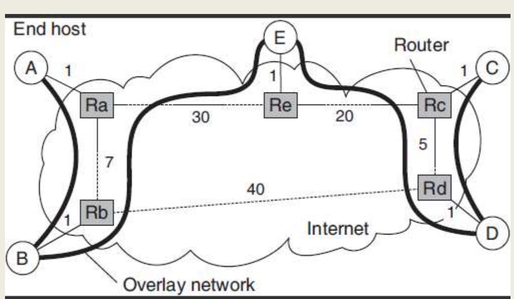


APPLICATION LEVEL TREE-BASED MULTICASTING

- Application level multi-casting
  - Nodes organize into an overlay network
  - Network routers not involved in group membership
  - Group membership is managed at the application level (A2)
- Downside:
  - Application-level routing likely less efficient than network-level
  - Necessary tradeoff until having better multicasting protocols at lower layers
- Overlay topologies
  - TREE: top-down, unique paths between nodes
  - MESH: nodes have multiple neighbors; multiple paths between nodes

MULTICAST TREE METRICS

- Measure quality of application-level multicast tree
- **Link stress:** is defined per link, counts how often a packet crosses same link (***ideally not more than 1***)
- **Stretch**: ratio in delay between two nodes in the overlay vs. the underlying networks



MULTICAST TREE METRICS - 2

- **Stretch (Relative Delay Penalty RDP)** for B to C routes:
- *Overlay:* B→Rb→Ra→Re→E→Re→Rc→Rd→D→Rd→Rc→ C = 73
- *Underlying:* B→Rb→Rd→Rc→C = 47
- 73 / 47 = 1.55

- **Tree cost:** Overall cost of the overlay network
- Ideally would like to minimize network costs
- Find a minimal spanning tree which minimizes total time for disseminating information

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QUESTIONS

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EXTRA SLIDES

39