Delay and Disruption Tolerant Networks

An Overview

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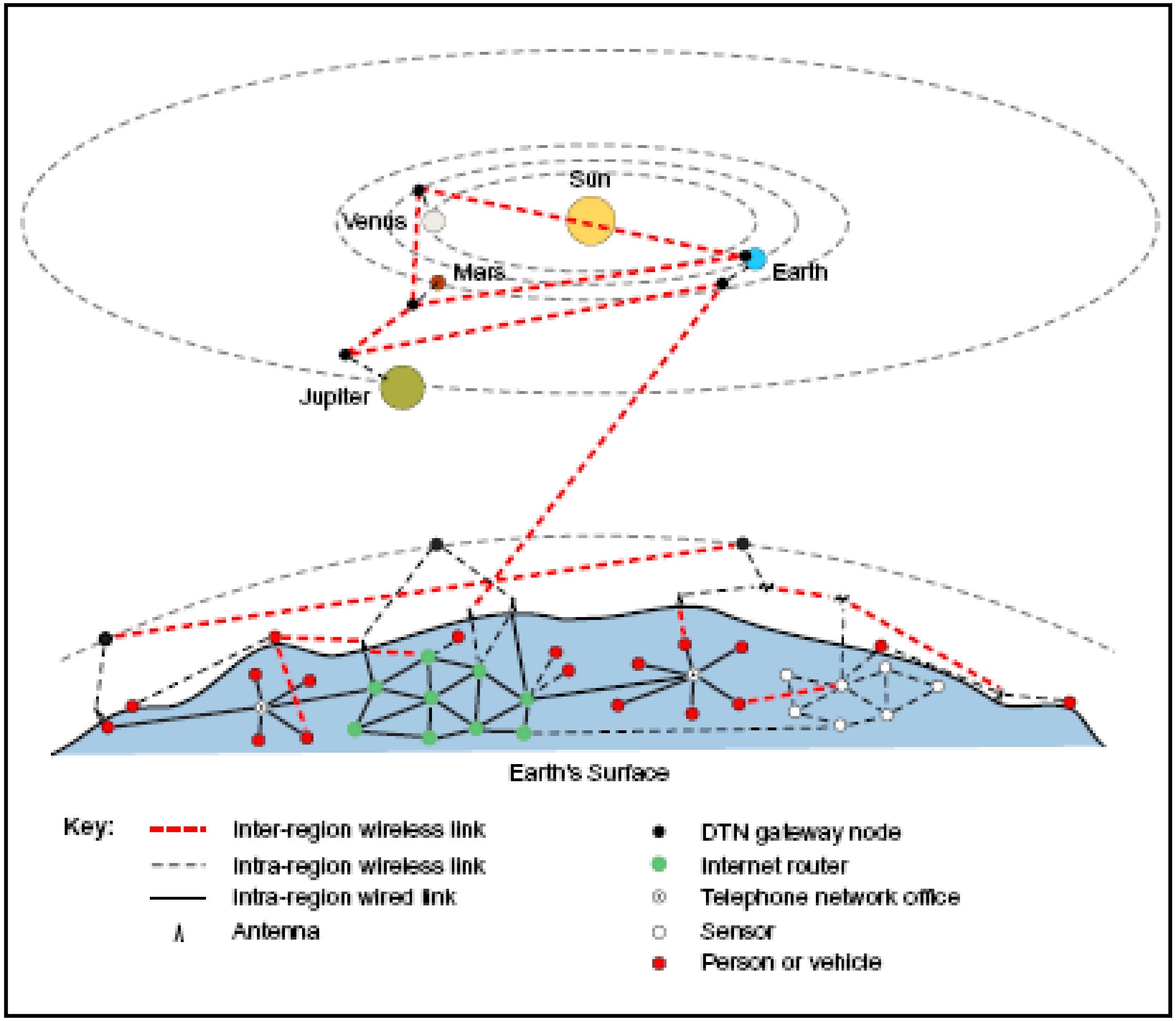
Who Is Working On Delay Tolerant Networks

- NASA through the Delay Tolerant Network Research Group (DTNRG)
  - DTNRG members research aspects of delay-tolerant networking in a number of ways including academic publications, technical specifications, several active mailing lists, and code (reference implementation) development.
  - https://sites.google.com/site/dtnresgroup/home
  - Active research on-going at JPL
- Internet Engineering Task Force (IETF)
  - https://datatracker.ietf.org/doc/search/?name=DTN&sort=&rfcs=on&activedrafts=on
- InterPlanetary Networking Special Interest Group (IPNSIG)
  - It's mission is to realize a functional and scalable system of interplanetary data communications before the year 2020.
  - http://ipnsig.org/about-us/
- Vint Cerf, one of the real founders of the Internet, and the co-developer of the TCP/IP protocols, and a VP at Google, is one of the big proponents of DTN protocols

What is a Delay Tolerant Network

- A delay tolerant network (DTN) (also often called disruption tolerant) is a network of regional networks.
  - It is an overlay on top of regional networks, including the Internet
- A DTN is designed to operate effectively over extreme distances such as those encountered in space communications or on an interplanetary scale.
  - Originally investigated for long latency situations measured in hours or days
  - Similar problems can also occur over more modest distances when interference is extreme or network resources are severely overburdened
- A DTN requires hardware that can store large amounts of data
  - The media must be able to survive extended power loss and system restarts.
  - Ideal technologies for this purpose include hard drives and high-volume flash memory.
  - The data stored on these media must be organized and prioritized by software that ensures accurate and reliable store-and-forward functionality.
  - The data must be immediately accessible at any time.
- Vint Cerf, one of the real founders of the Internet, and the co-developer of the TCP/IP protocols, and a VP at Google, is one of the big proponents of DTN protocols
  - Active research on-going at JPL

A Space Network Requiring Delay Tolerant Technology



Potential Users of DTNs (1)

- DTNs support interoperability of regional networks by supporting long delays between regional networks
  - The DTN provides translation services between the various networks
- Terrestrial Mobile Networks
  - Some of these networks may become unexpectedly partitioned due to node mobility or changes in signal strength (e.g. RF interference), while others may be partitioned in a periodic, predictable manner.
  - For example, a commuter bus could act as a store and forward message switch with only limited-range RF communication capability. As it travels from place to place, it provides a form of message switching service to its nearby clients to communicate with distant parties it will visit in the future.
- Exotic Media Networks
  - Exotic communication media includes near-Earth satellite communications, very long distance radio or optical links (e.g. deep space communications with light propagation delays in the seconds or minutes), acoustic links in air or water, and some free-space optical communications.
  - These systems may be subject to high latencies with predictable interruption (e.g. due to planetary dynamics or the passing of a scheduled ship), may suffer outage due to environmental conditions (e.g. weather), or may provide a predictably-available store-and-forward network service that is only occasionally available (e.g. low-earth orbiting satellites that "pass" by periodically each day)
  - Practical example is the Mars – Earth Interplanetary Internet
    - When the Mars and the Earth are at the opposite sides of the Sun, the distance is the largest: approximately: 378 million km. The time needed for an electromagnetic wave to cover this distance is approximately: 21 minute. Even at the closest distance between Mars and Earth is 78 million km, the time in this case is: 4.3 min.

Potential Users of DTNs (2)

- Military Ad-Hoc Networks
  - These systems may operate in hostile environments where mobility, environmental factors, or intentional jamming may be cause for disconnection.
  - Data traffic may have to compete for bandwidth with other services at higher priority
    - As an example, data traffic may have to unexpectedly wait several seconds or more while high-priority voice traffic is carried on the same underlying links.
  - Such systems often have especially strong infrastructure protection requirements
- Sensor/Actuator Networks
  - These networks are frequently characterized by extremely limited end-node power, memory, and CPU capability
  - They are envisioned to exist at tremendous scale, with possibly thousands or millions of nodes per network
  - Communication within these networks is often *scheduled* to conserve power, and sets of nodes are frequently named (or addressed) only in aggregate
  - They typically employ "proxy" nodes to translate Internet protocols to the sensor network native protocols

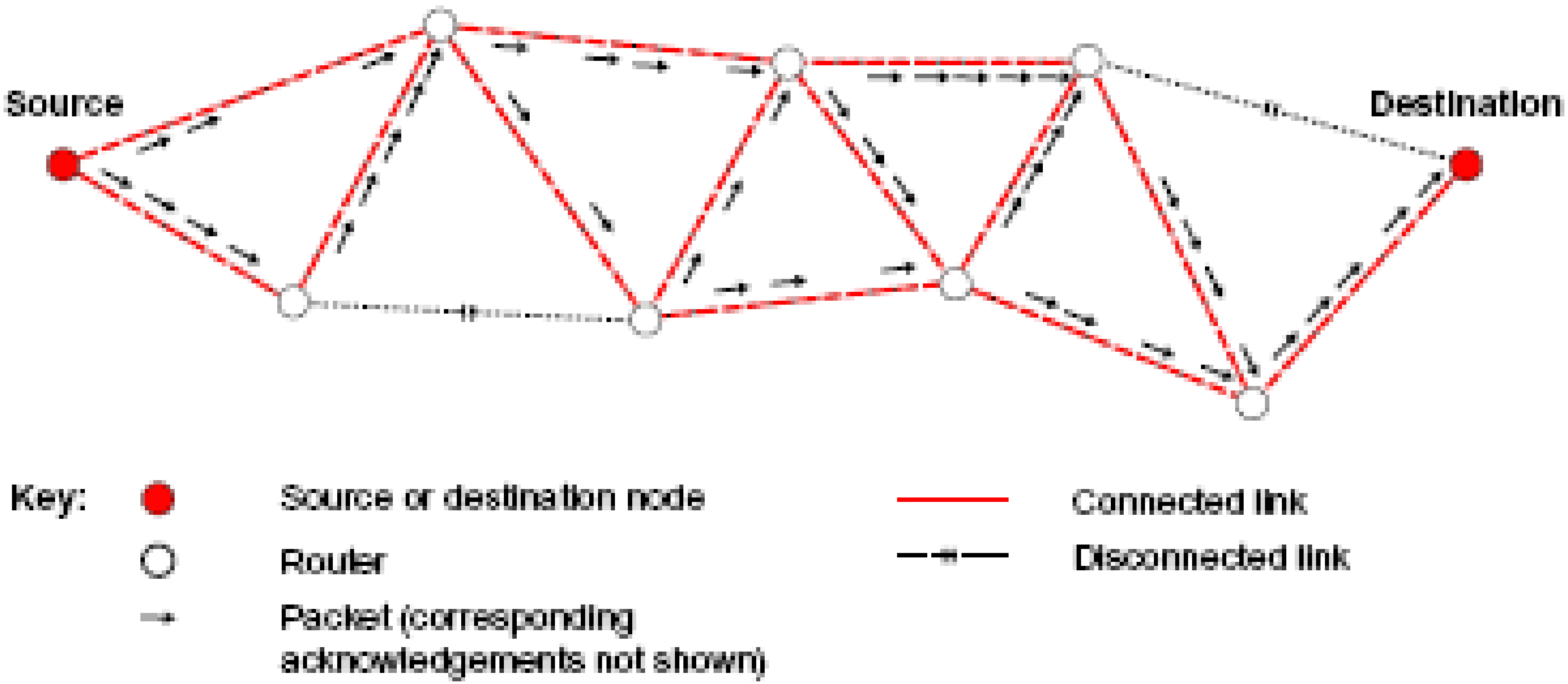
Standards Governing DTNs

- Consultative Committee for Space Data Systems, NASA, CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1, Blue Book, September 2015
  - Now recommended for all space ventures requiring DTNs, regardless of the underlying physical network
- Network Working Group, IETF, Bundle Protocol Specification, RFC 5050, JPL, Nov. 2007
- Active Internet Drafts at
  - https://datatracker.ietf.org/doc/search/?name=DTN&sort=&rfcs=on&activedrafts=on

Characteristics of Packet Switching Networks

- What are packets?
  - Packets are pieces of a complete block of data
  - Travel independently from source to destination
  - Each packet contains both a header and a part of the message body
  - Packets are rebuilt into a complete message at the destination
  - Packets do not have to arrive in order
- Usability of the Internet is based on several key assumptions
  - Continuous, bidirectional end-to-end path
  - Short round trips between routers on the network
  - Symmetric data rates
  - Low error rates – in high bit error rate (BER) environments error correction techniques are used

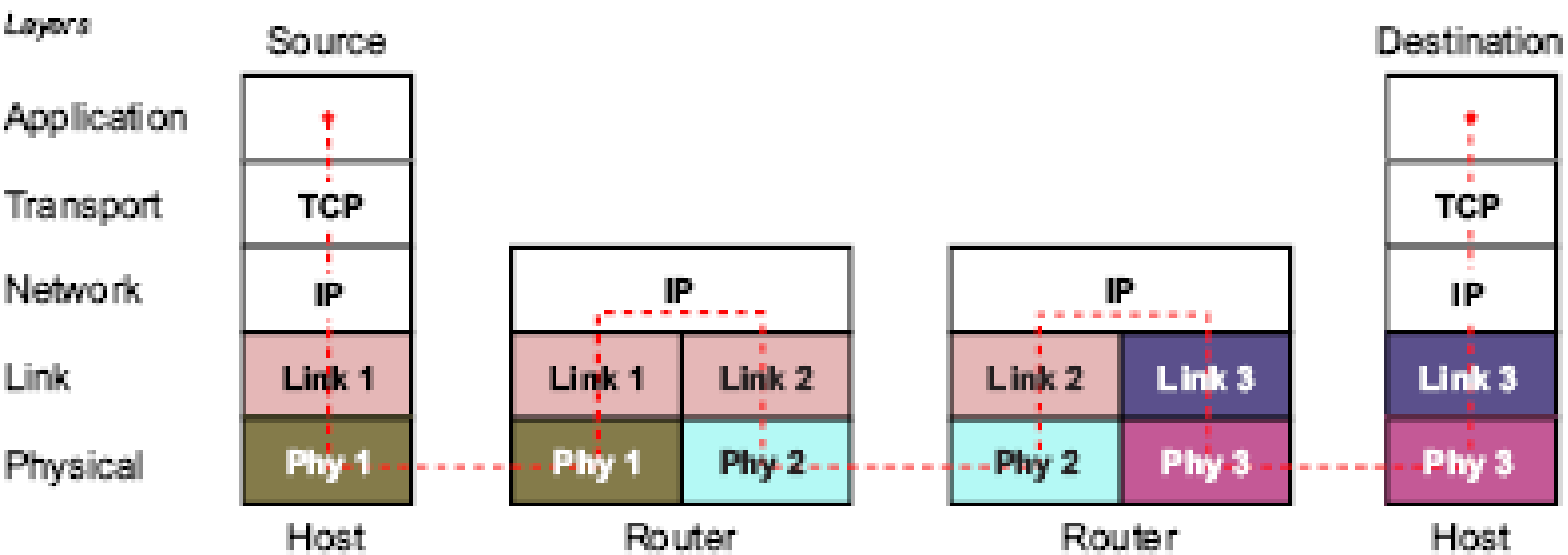
Routing Over The Internet



Protocol Layers

- In simplified form networks are implemented with five basic layers
  - Application Layer – Generates or consumes data
  - Transport Layer – Source-to-destination segmentation of messages into message pieces (TCP is used on the Internet)
  - Network Layer – Source-to-destination routing of addressed message pieces through intermediate routers
  - Link Layer – Link-to-link transmission and reception of addressed message pieces, with error control (e.g. Ethernet, PPP, modems, etc.)
  - Physical layer – Link-to-link transmission and reception of bit streams over a physical media
- Routers are typically used to implement the middle three layers and interface with the physical layer

Typical Internet Implementation of Layered Architecture

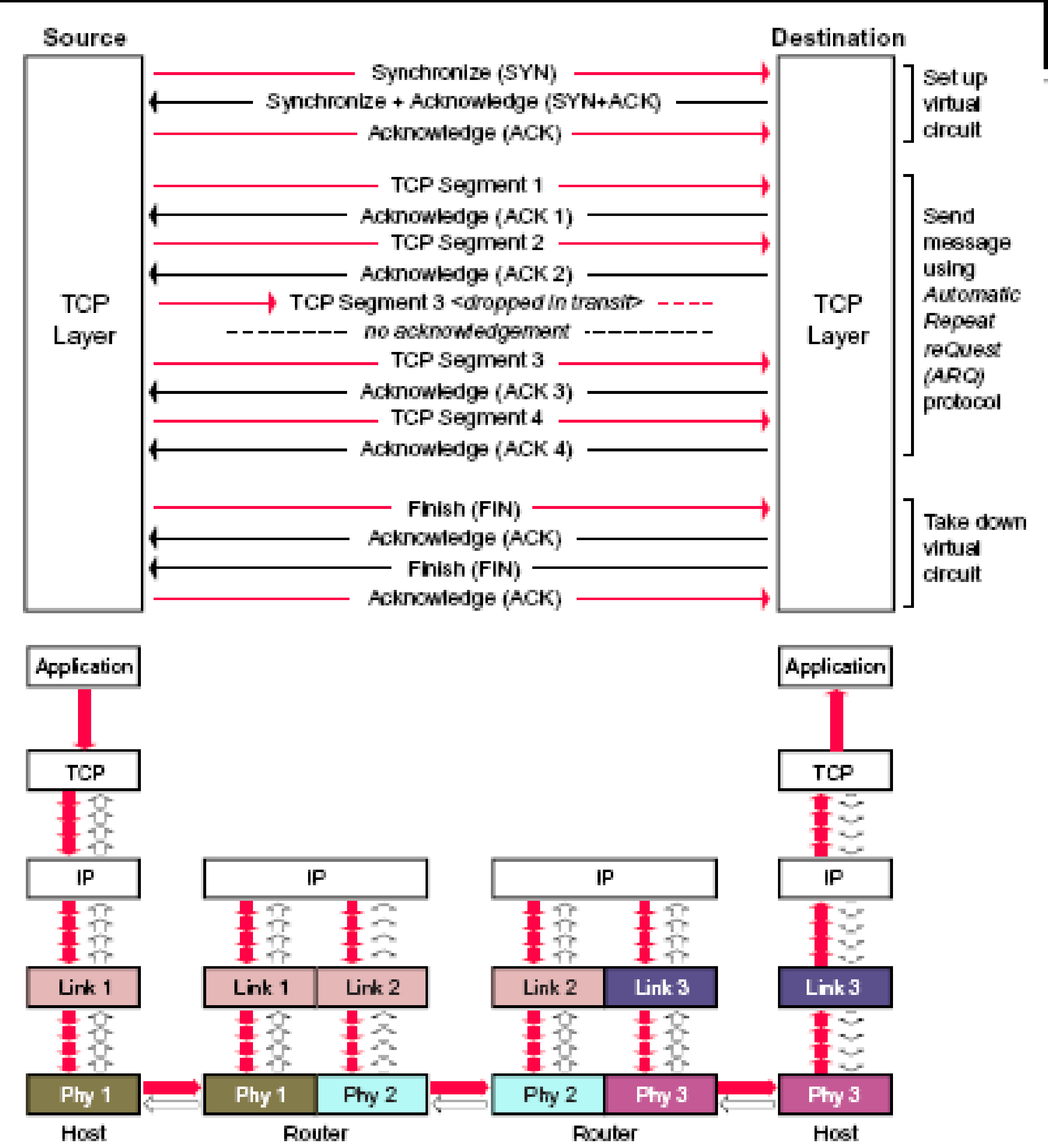


Note that there is standardization down to the IP layer, but that the Link and Physical layers may vary according to the various hardware and communications systems available

Conversational Protocols in Low Latency Networks

- At each layer acknowledgements occur
- TCP employs a three step process to transmit a message
  - Set up – the Hello handshake
  - Segment transfer and acknowledgement
  - Take down – the Goodbye handshake

Acknowledgements in the TCP/IP Model



Why Do We Need New Protocols to Support DTNs

Internet Assumptions	DTN Reality

• Continuous bi-directional end-to-end paths
  • Required to support end-to-end interaction
	• Intermittent Connectivity
	  • No end-to-end path from source to destination does not allow TCP/IP transmission
	  • When no path exists a network partition is said to occur

• Short round-trips
  • Short, consistent network delays in both directions in sending packets and receiving acknowledgements
	• Long or Variable Delay
	  • Long propagation delays between nodes or variable queuing delays at nodes can lead to TCP/IP failure – TCP requires rapid acknowledgements to avoid timeouts

• Symmetric data rates in both directions	• Asymmetric Data Rates • Large asymmetries can defeat conversational protocols

• Low error rates	• Higher Bit Error Rates
	  • With end-to-end protocols and high BERs large retransmission rates can swamp a network
	  • Experiments on more volatile military networks showed difficulties of transmitting large data blocks over networks with high BERs

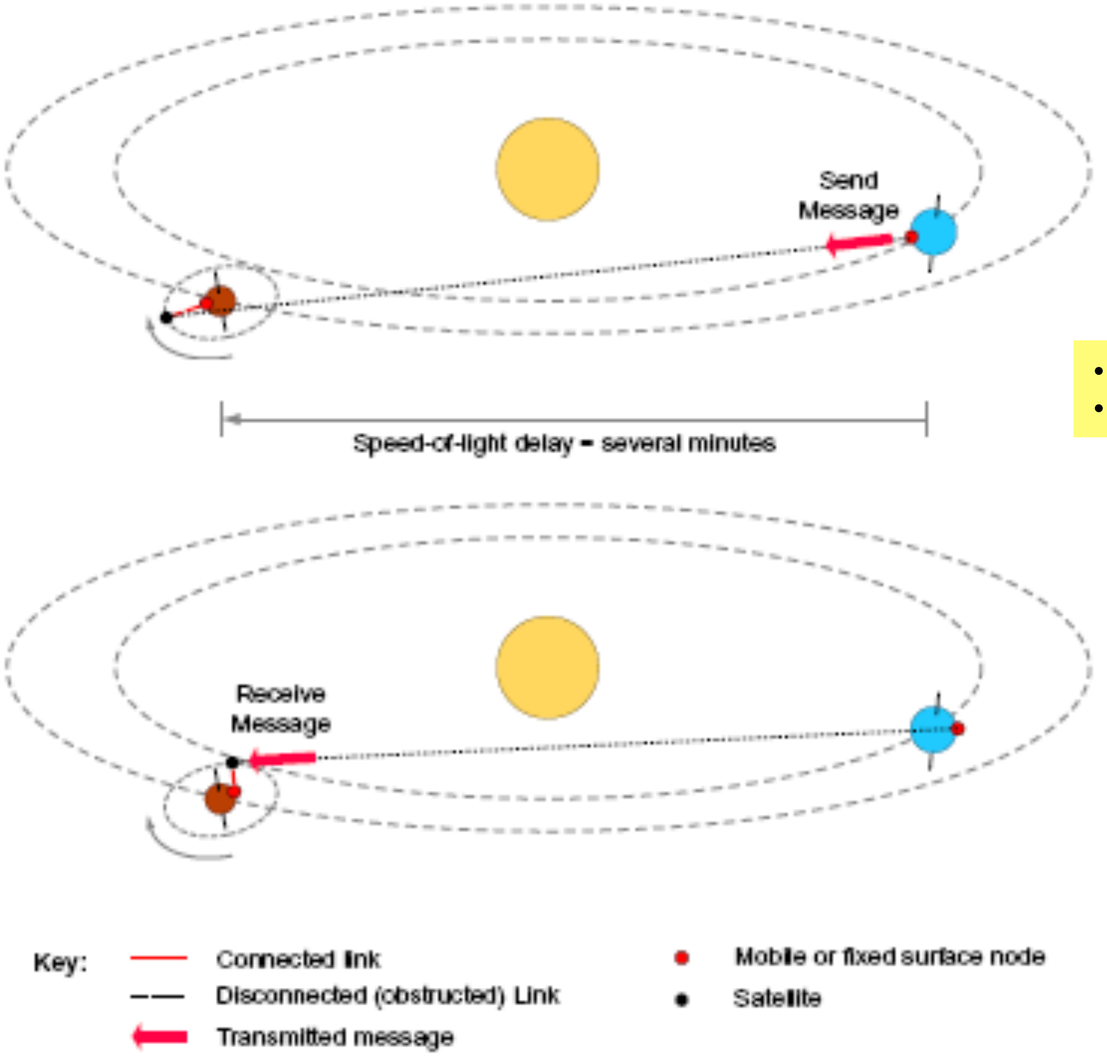
DTN Networks Have Turned To Store and Forward Message Switching

- Store and Forward Message Switching
  - Move the entire message from node to node, not end-to-end
  - Storage can hold large amounts of data, indefinitely if necessary
- Store and forward solves the following problems
  - Missing communications link between the source and destination
  - Great variability between send and receive speeds
  - Higher error rates at some point in the route, requiring alternative means to complete a data transfer
- DTNs support communications between intermittently connected nodes by isolating delays with store and forward technique

Intermittent Connectivity and Opportunistic Contacts

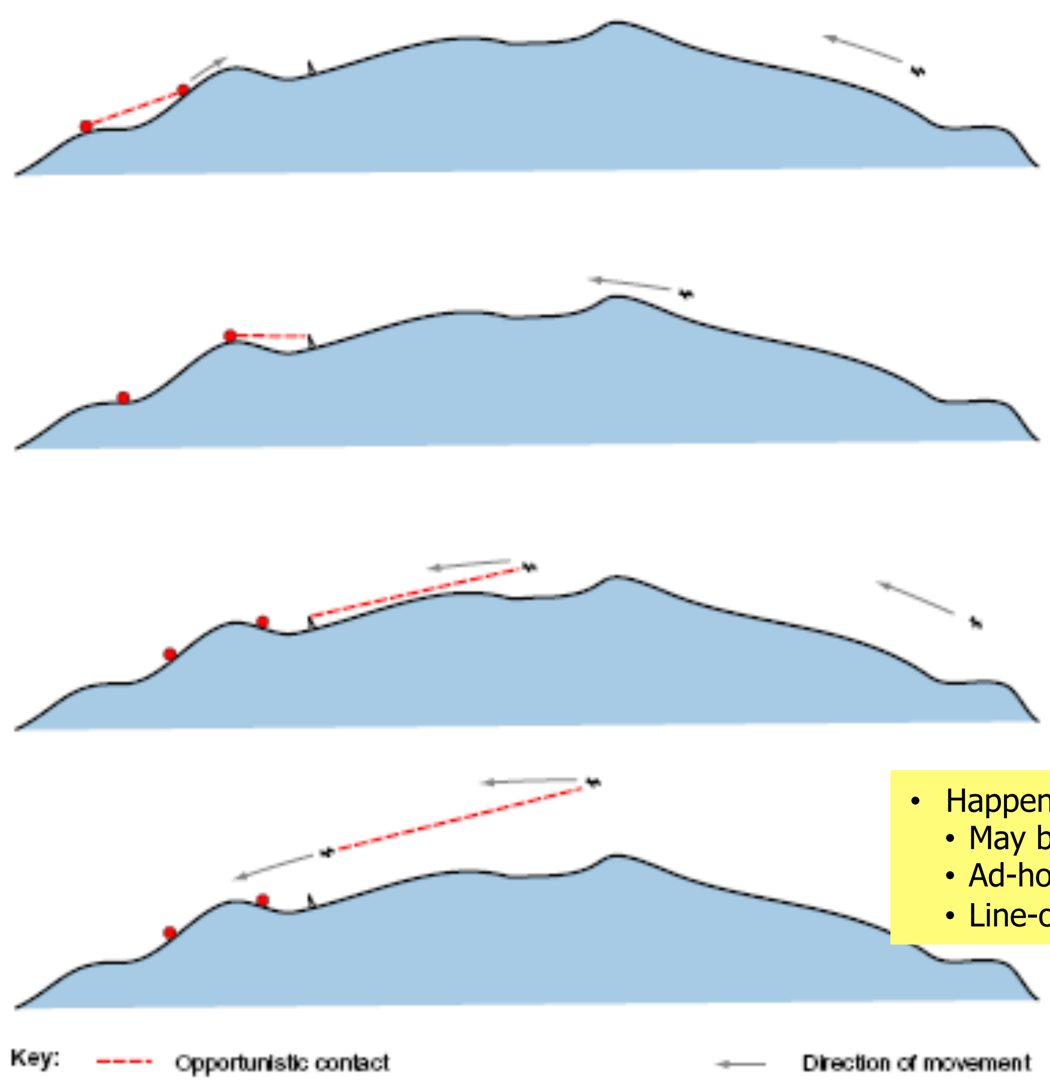
- Intermittent Connectivity
  - Scheduled forwarding of data in a store and forward network based on preplanned knowledge
  - Examples include predetermined line-of-sight (LOS) between vehicles, aircraft, satellites or even planets
- Opportunistic Contacts
  - Sender and receiver make contact at unscheduled times
  - Moving people, aircraft and/or satellites can make contact when they are within LOS and close enough to communicate
  - An example would be combat vehicles moving on a dynamic battlefield

Scheduled Contacts



- Predictable locations allow for scheduled
- transmissions

Opportunistic Contacts

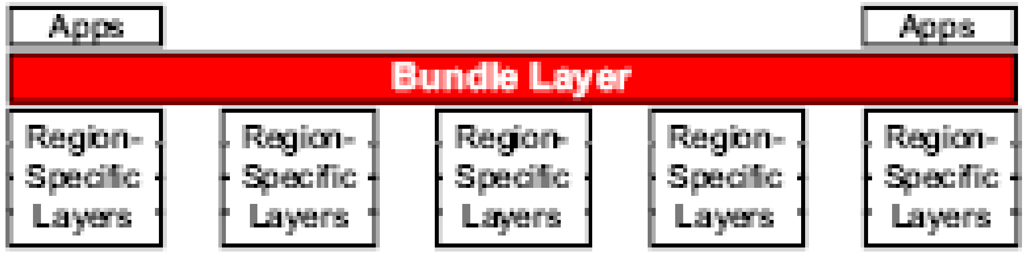


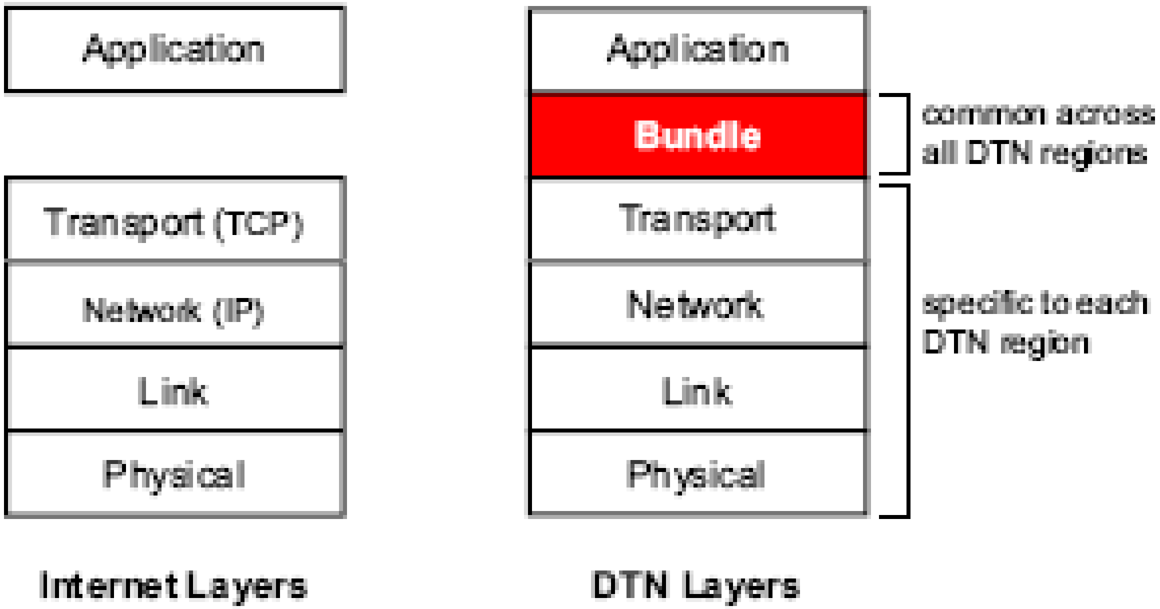
- Happens opportunistically as opposed to a scheduled time
  - May be searching for an available signal to transmit over
  - Ad-hoc mobile networks may operate this way
  - Line-of-sight opportunities

Implementing a DTN – The Bundle Layer

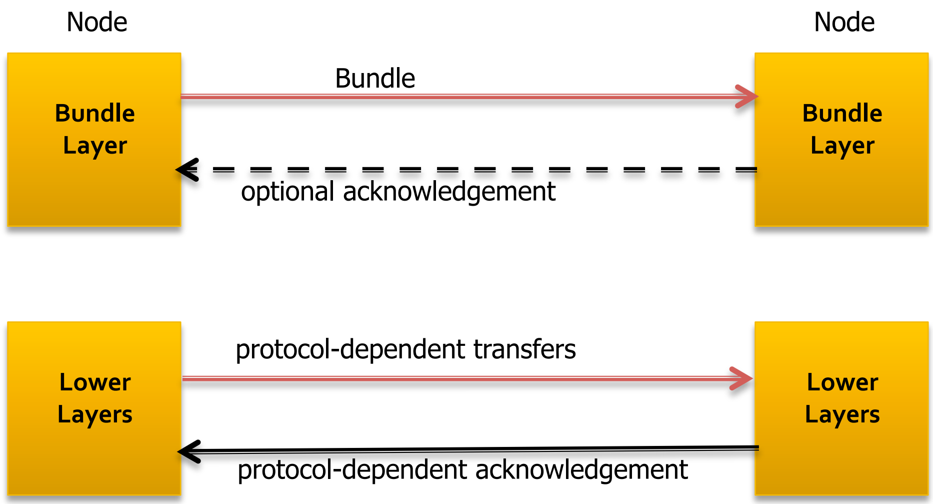
- In order to implement DTNs the Bundle Layer Protocol has been defined
  - Implements store and forward protocol layer on top of heterogeneous region specific lower layers
  - Bundle layer stores and forwards bundles (also called messages) or bundle fragments between nodes (not necessarily from source to destination)
  - Lower layers are based on their appropriateness to a specific region's communication characteristics

The Bundle Overlay





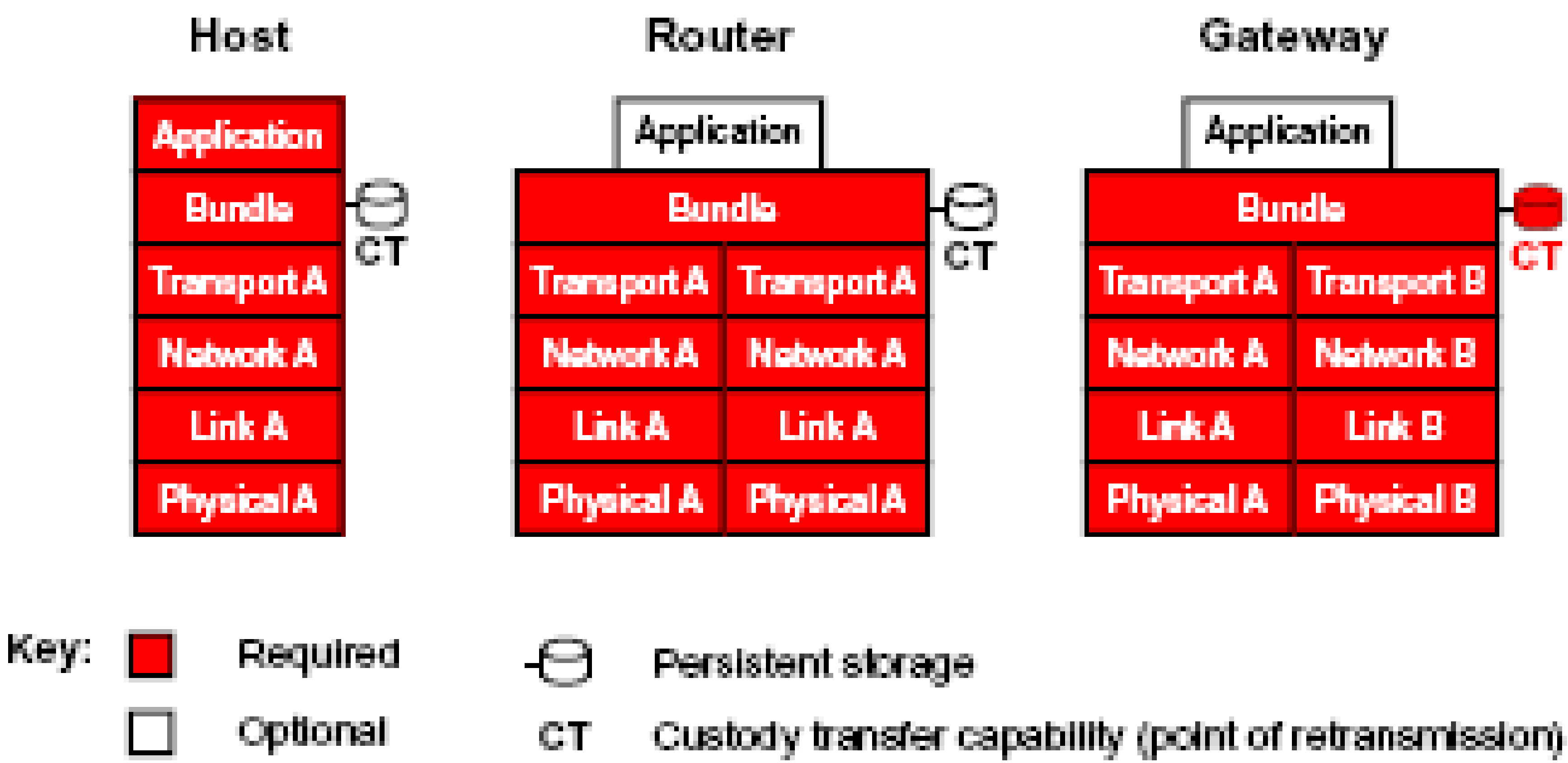
The Bundle Protocol is Non-Conversational



DTN Nodes

- A DTN node is an entity with a bundle layer
  - Node may be a host, router, or gateway acting as a source, destination or intermediate forwarder of bundles
- Host
  - Sends and/or receives bundles – it is a source or destination
  - Does not forward bundles
- Router
  - Forwards bundles within a single DTN region
  - Optionally may be a host
  - Operates within a single DTN region
  - May optionally support custody transfers
- Gateway
  - Forwards bundles between two or more DTN regions
  - Provides conversions between spanned regions
  - Optionally may be a host

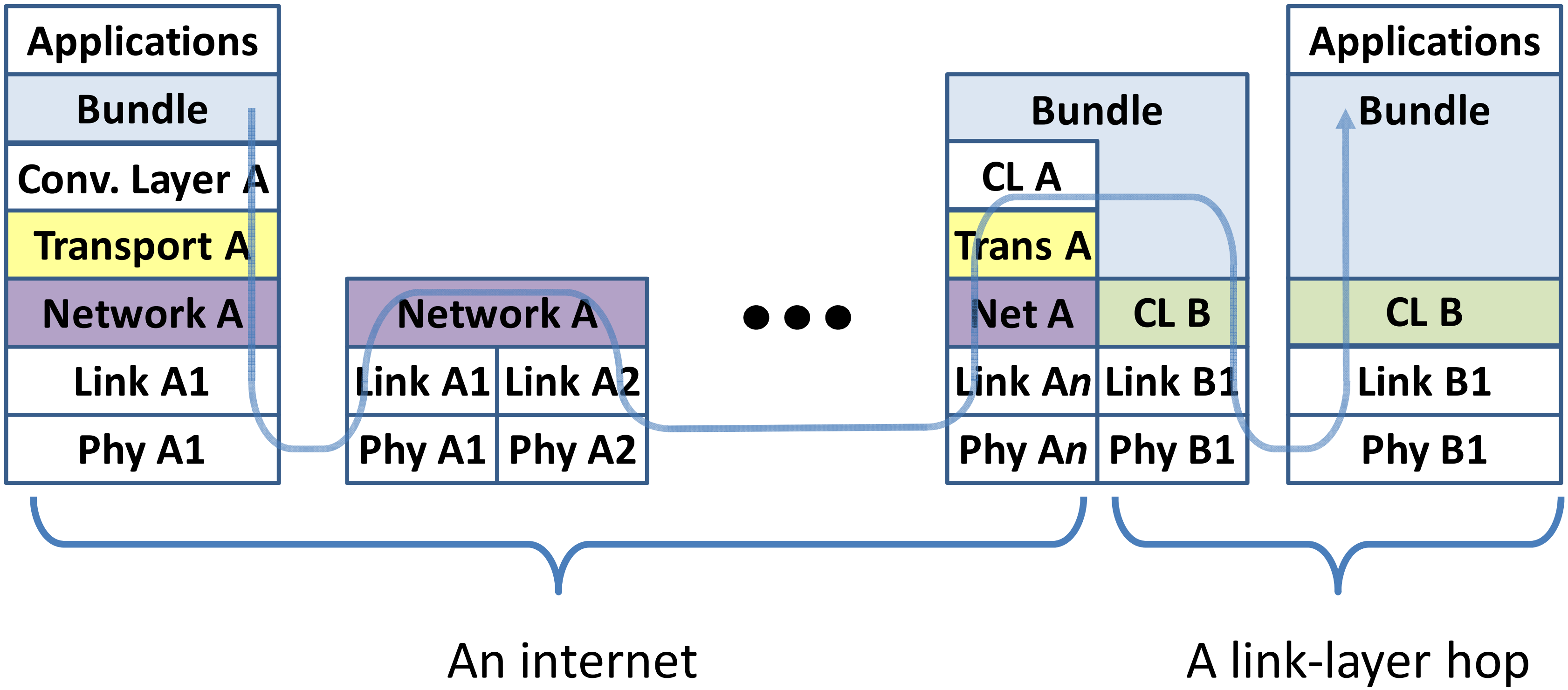
Three Types of DTN Nodes



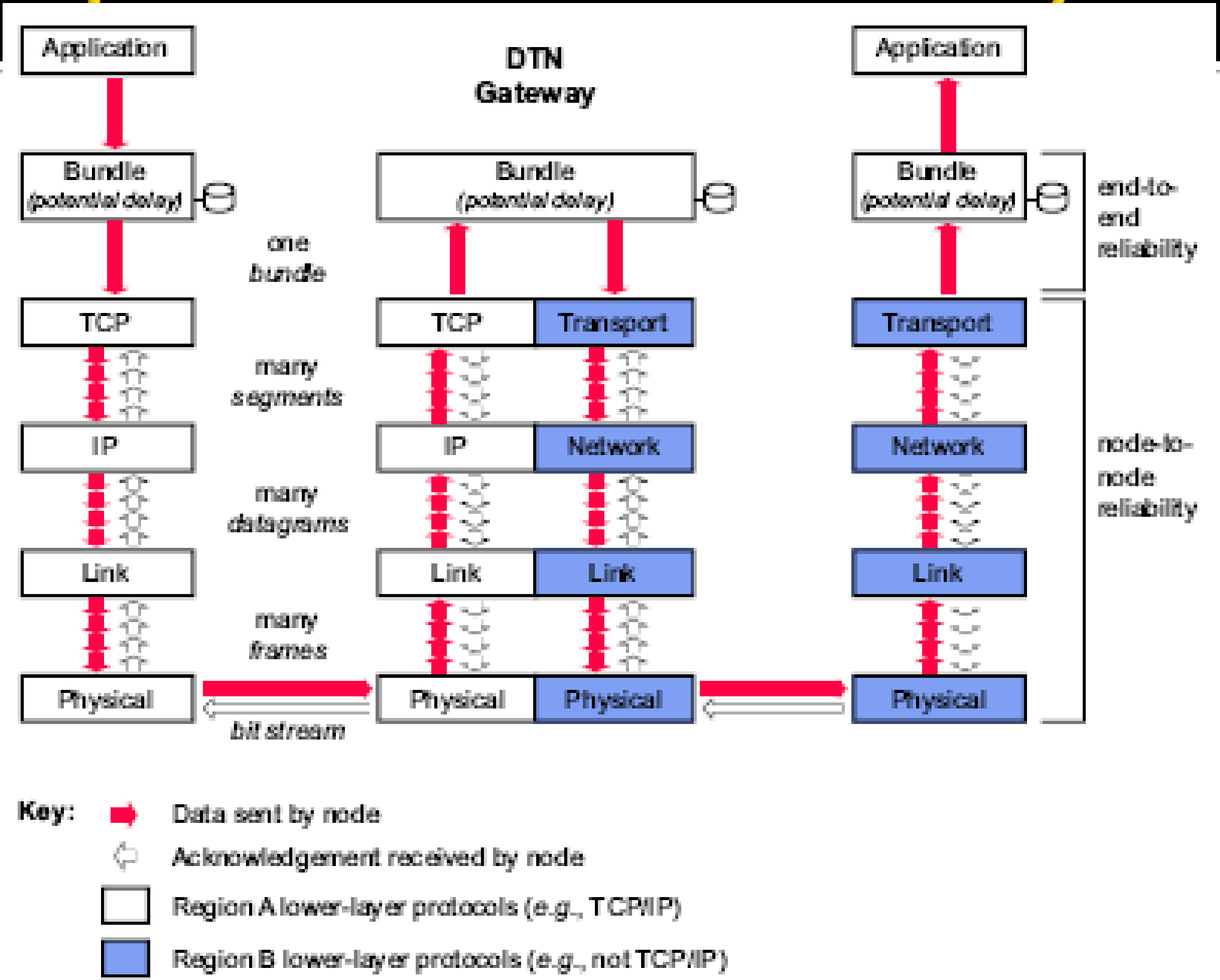
Solving the Delay Problem

- DTN routers and gateways terminate transport bundles at the bundle layer
  - End-to-end messaging is supported only at the bundle layer
  - Bundles can be segmented at the bundle layer, but are usually delivered in one piece to the transport layer
  - Bundle layer provides a surrogate for end-to-end sources and destinations
  - When the next step in the route can be completed the communication continues
  - Isolates low-delay network regions from problems in higher delay regions

The Bundle Protocol Provides an End-to-End Delivery Service



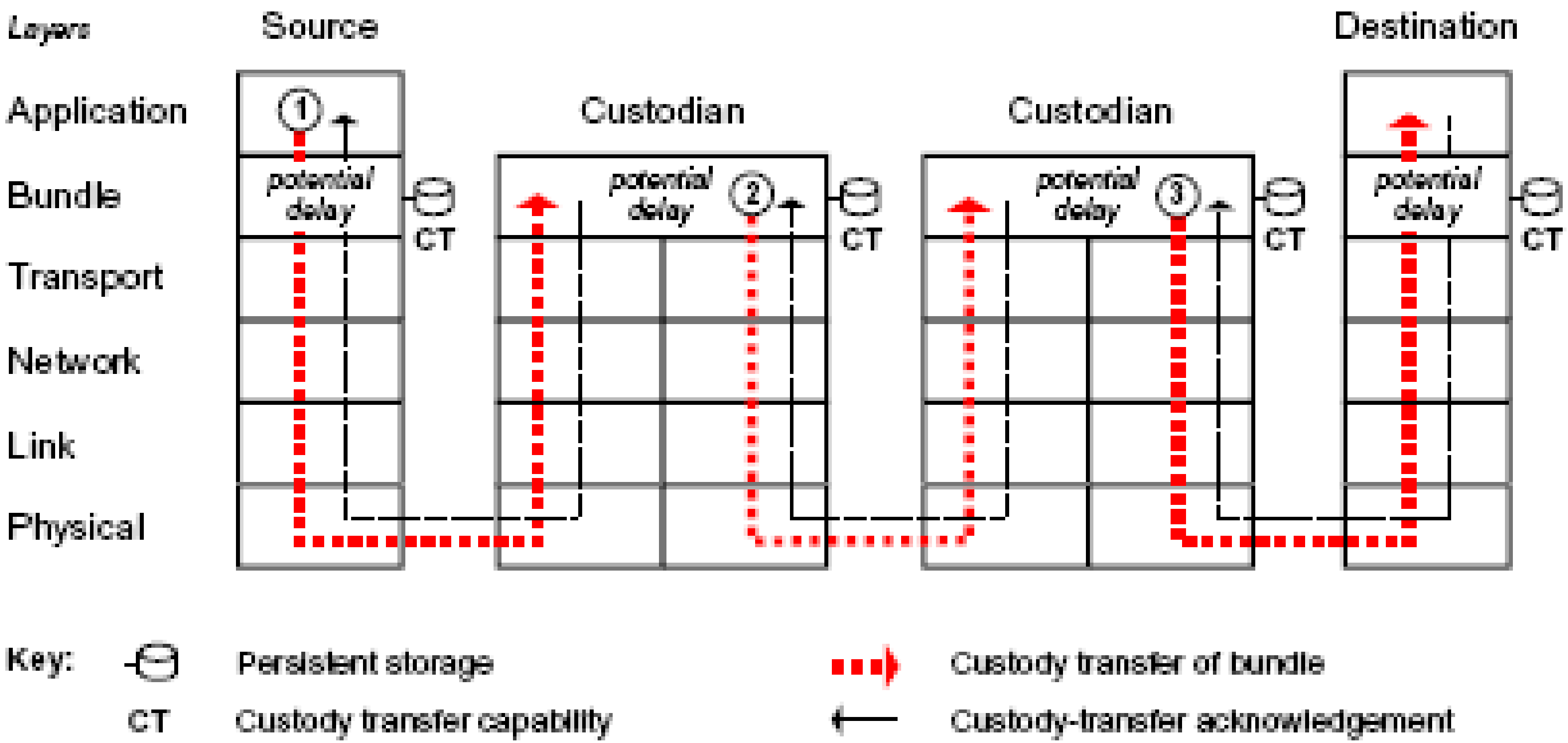
Sample DTN With Gateway



The DTN Bundle Can Solve the Delay Problem

- DTNs support node-to-node transmissions at both the transport and bundle layer between:
  - Source and Custodian
  - Two custodians
  - Custodian and Destination
- End-to-end reliability is only implemented in a step-wise manner through the bundle layer
  - Custody transfers are used to implement node-to-node retransmissions
  - Request to transfer bundle and acknowledgement of custody transfer handled at the bundle layer
  - Transfer protocol has a time-out parameter, after which entire bundle is retransmitted
- Bundle custodian must store a bundle until:
  - Another node accepts custody or
  - The bundle's time to live expires (it is discarded at that point)
- Custody transfers do not guarantee end-to-end reliability
  - This requires both custody transfer and return receipt (described shortly)
  - If return receipt is requested source must retain a copy of the bundle until receipt is received
    - Without receipt bundle is retransmitted

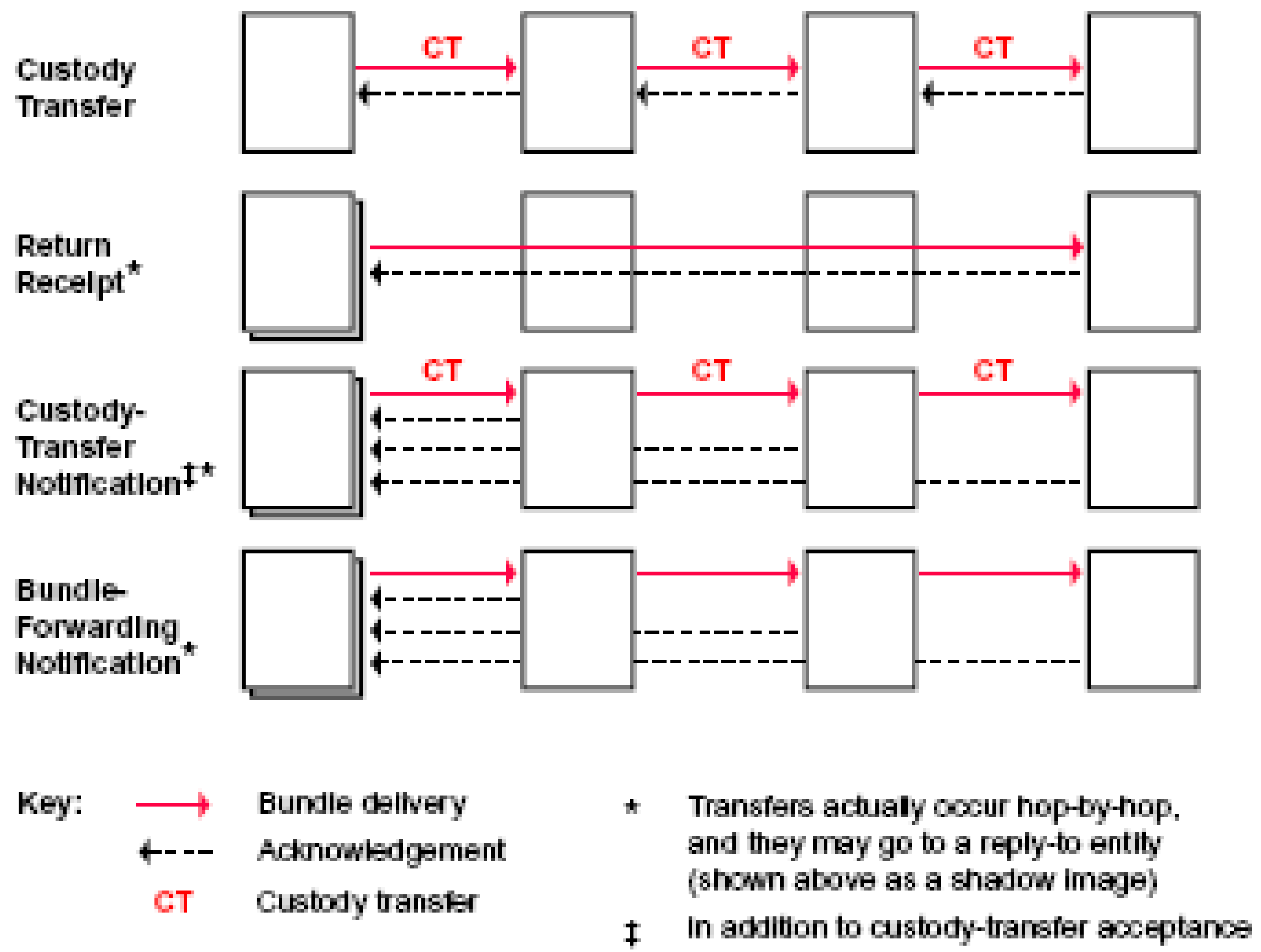
Custody Transfer Architecture



Bundling Classes of Service

- There are six bundling classes of service (CoS)
  - Custody Transfer
    - Delegation of retransmission responsibility to accepting node
    - Sending node recovers retransmission resources
    - Accepting node returns custodial acceptance acknowledgement
  - Return Receipt
    - Confirmation to the source that bundle has made it to destination
  - Custody-Transfer Notification
    - Notification to the source when any node along the route accepts a custody transfer of the bundle
  - Bundle-Forwarding Notification
    - Notification to the source whenever a bundle is forwarded
  - Priority of Delivery
    - Three modes – expedited, normal, bulk
  - Authentication
    - The method used to verify senders identity and the integrity of the message

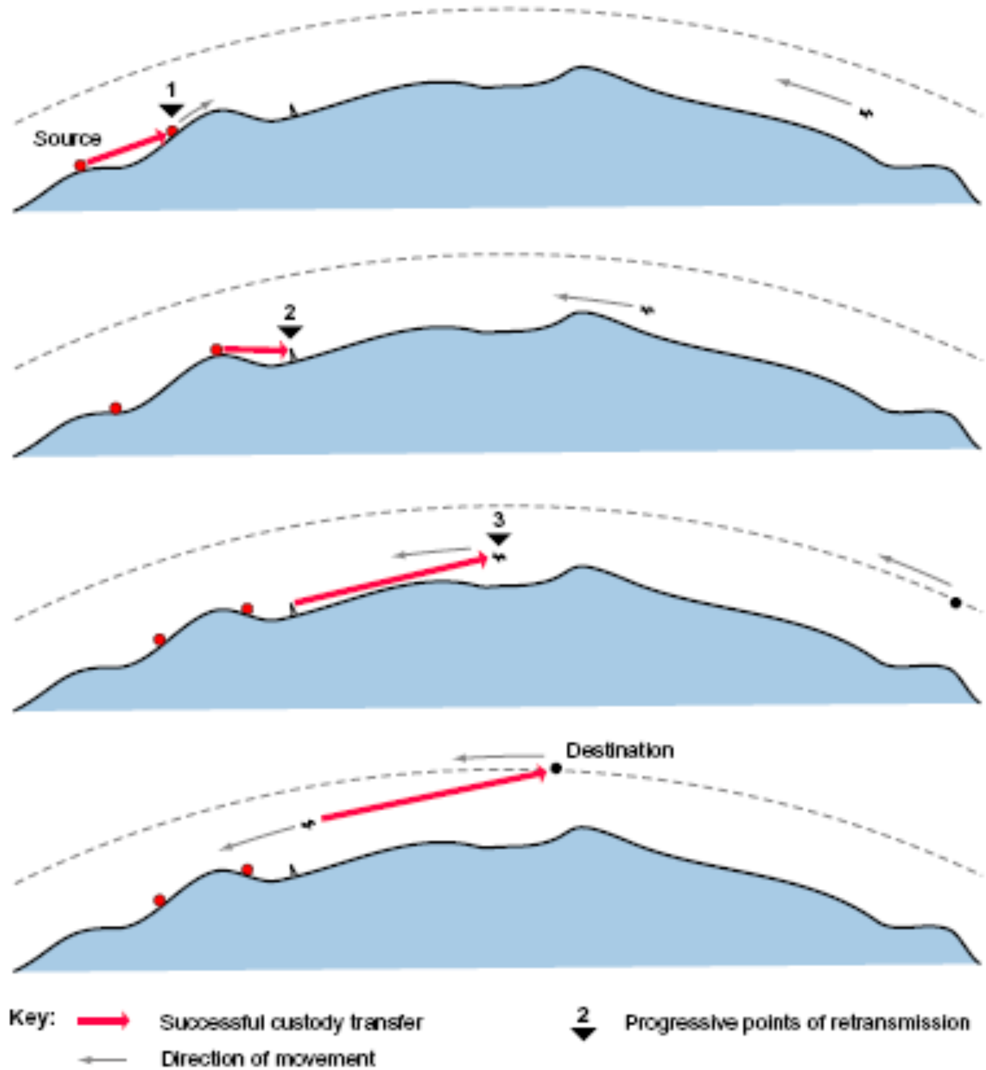
Acknowledgement Traffic for Classes of Service



DTN Traffic Types

- There are three types of traffic in DTNs
  - **Expedited packets** are always transmitted, reassembled and verified before data of any other class from a given source to a given destination
  - **Normal traffic** is sent after all expedited packets have been successfully assembled at their intended destination.
  - **Bulk traffic** is not dealt with until all packets of other classes from the same source and bound for the same destination have been successfully transmitted and reassembled.

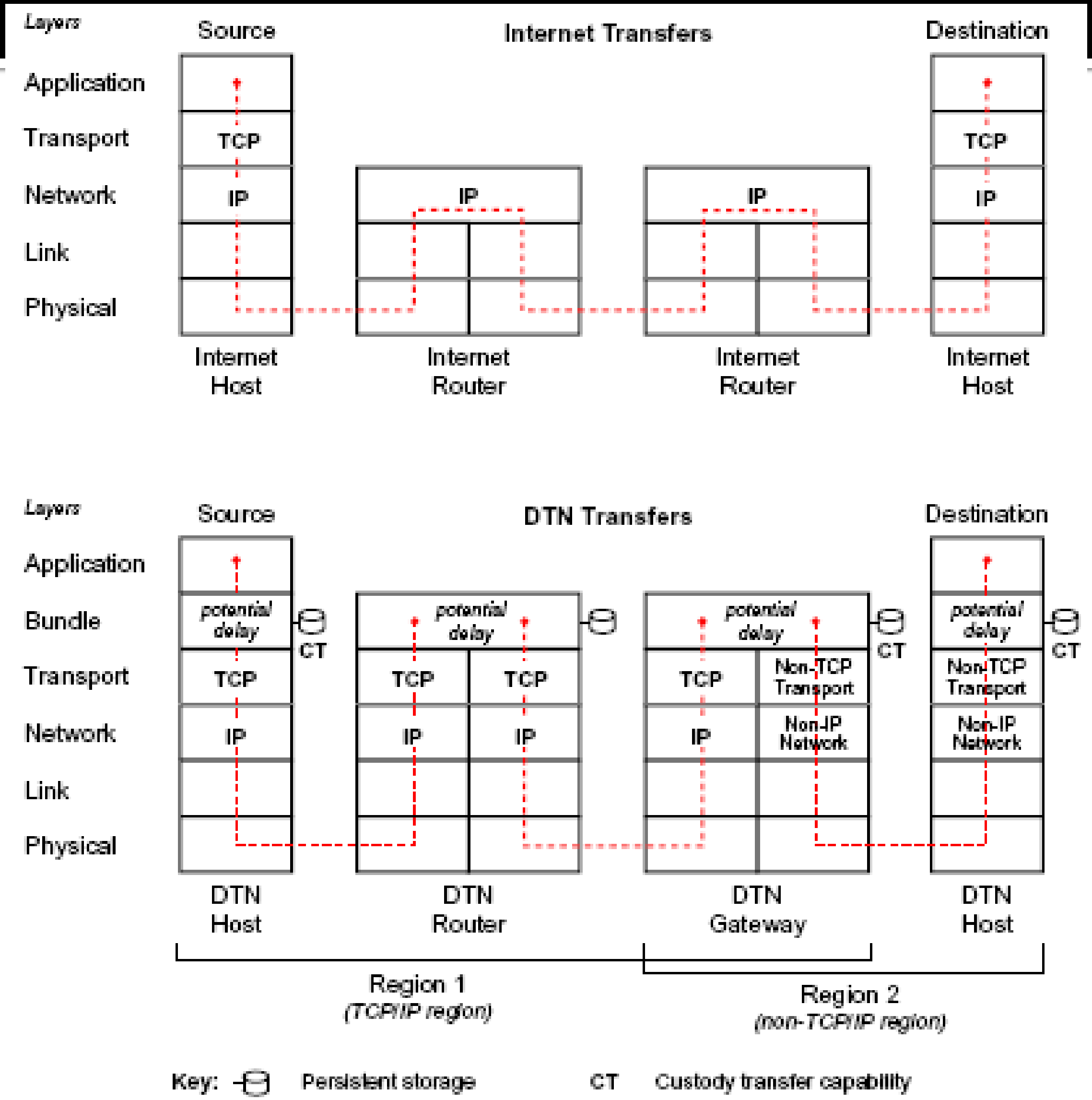
Using DTNs to Move Transmissions from Source to Destination



Comparing the Internet and a Delay Tolerant Network

- Internet
  - TCP/IP protocols used throughout
  - TCP manages reliable end-to-end delivery of message segments
  - IP required on all nodes
- Delay Tolerant Networks
  - Protocol stacks of all nodes include both bundle and transport layers
  - Gateways can run different lower layer protocols in their two stacks
  - DTNs can span different regions that use different lower layer protocols
  - DTNs have persistent storage requirements

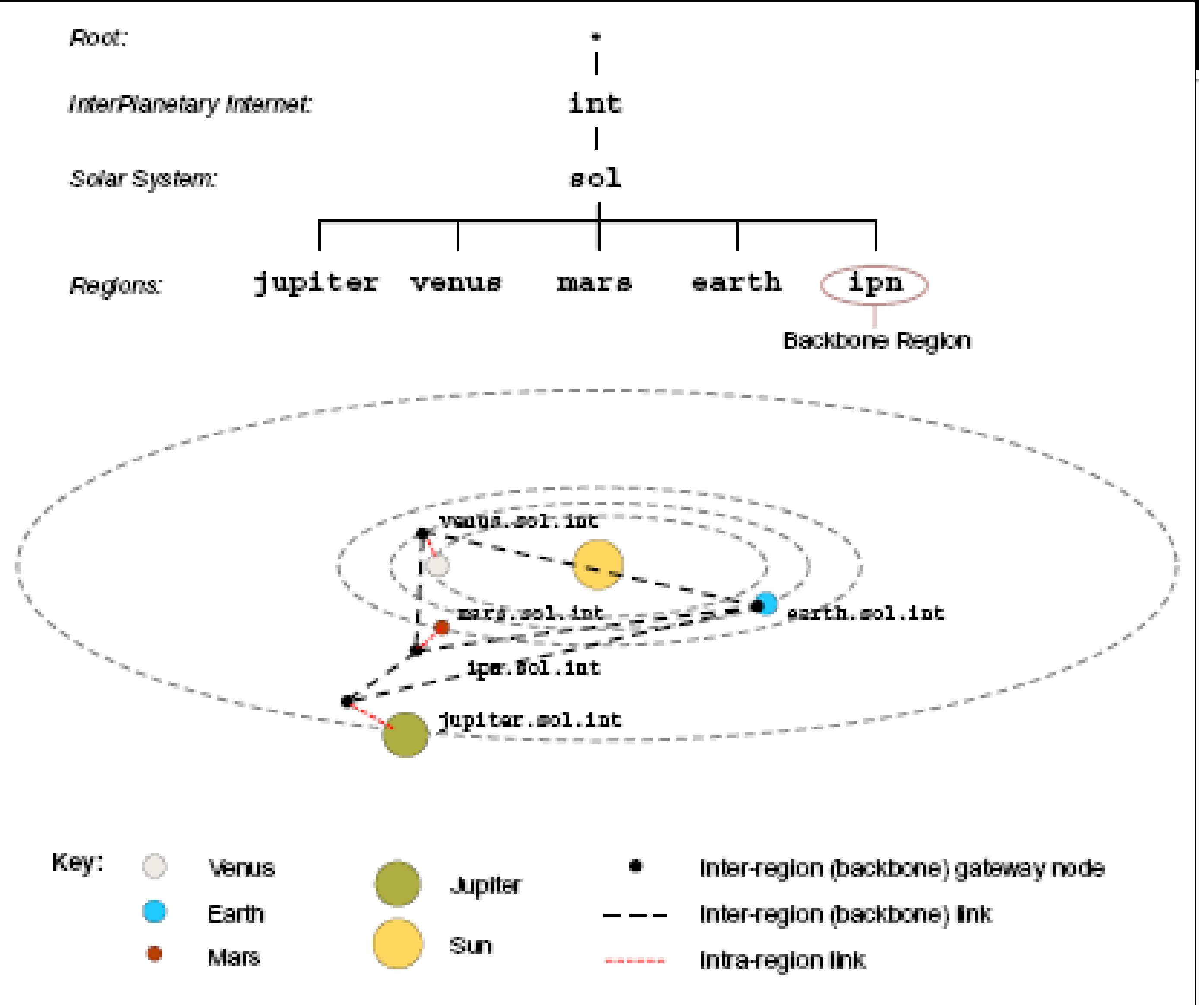
Internet Versus Sample DTN Architecture



DTN Regions

- A DTN is a network of networks
  - Each of the networks is a region
  - Each region is a homogeneous network
  - Each region has a unique *region ID* which is know by all other regions in the DTN
  - The *region ID* is part of each node's name
  - DTN Gateways have membership in two or more regions

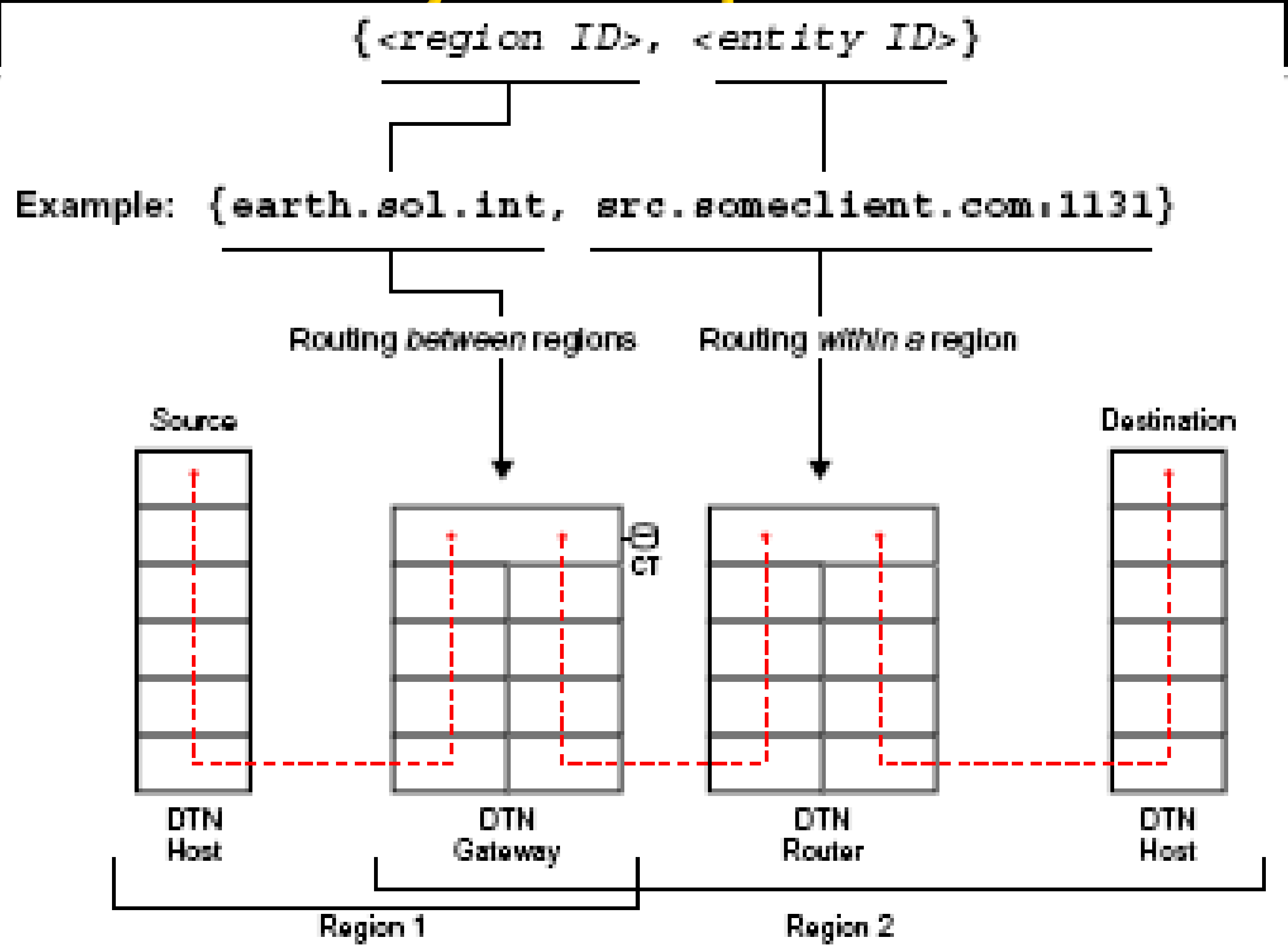
A Sample DTN


Root:
.
InterPlanetary Internet:
int
Solar System:
sol
Regions:
jupiter
venus
mars
earth
ipn
Backbone Region
venus.sol.int
mars.sol.int
earth.sol.int
ipn.sol.int
jupiter.sol.int
Key:
Venus
Earth
Mars
Jupiter
Sun
Inter-region (backbone) gateway node
Inter-region (backbone) link
Intra-region link

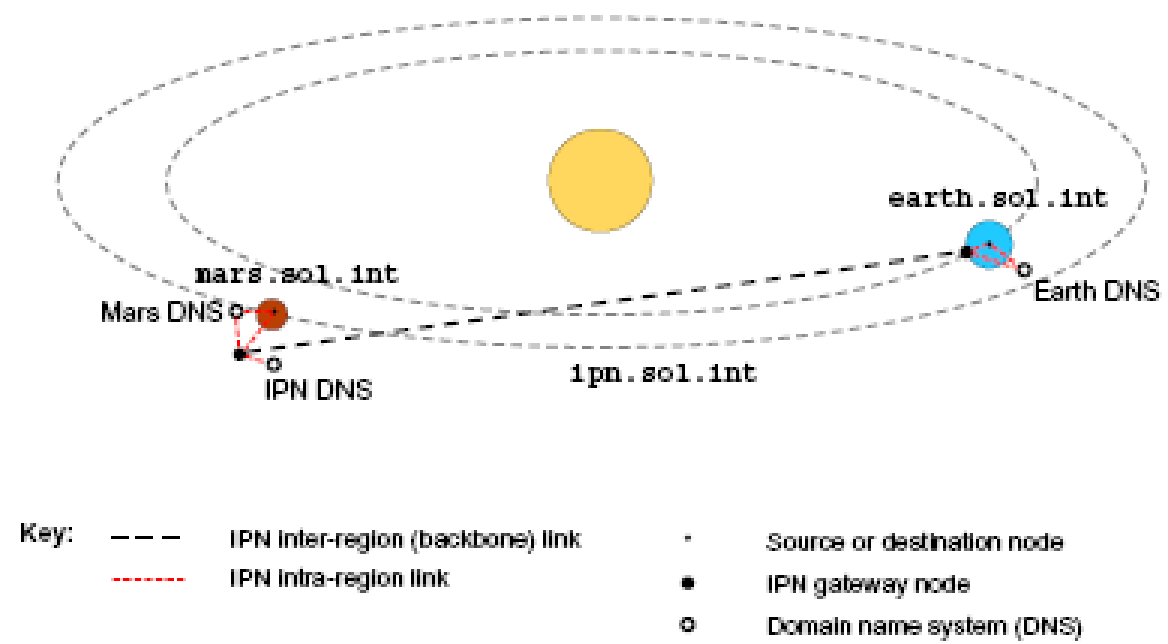
Names and Addresses in DTNs

- Each DTN has as two part name
  - *region ID*
  - *entity ID*
- Routing between regions is based only on the *region IDs*
  - These addresses are bound together through the DTN
  - Region IDs use the same name-space syntax as the Internet's Domain Name System (DNS)
- Routing within regions is based only on the *entity ID*
  - Each region may use a different mapping of *entity IDs* to addresses
  - Gateways have multiple *entity IDs*, one per region
  - An entity can be a host node, an application instance, a protocol, a port, or any other addressable object

Addressing Example



An Addressing Scheme for an Interplanetary Internet

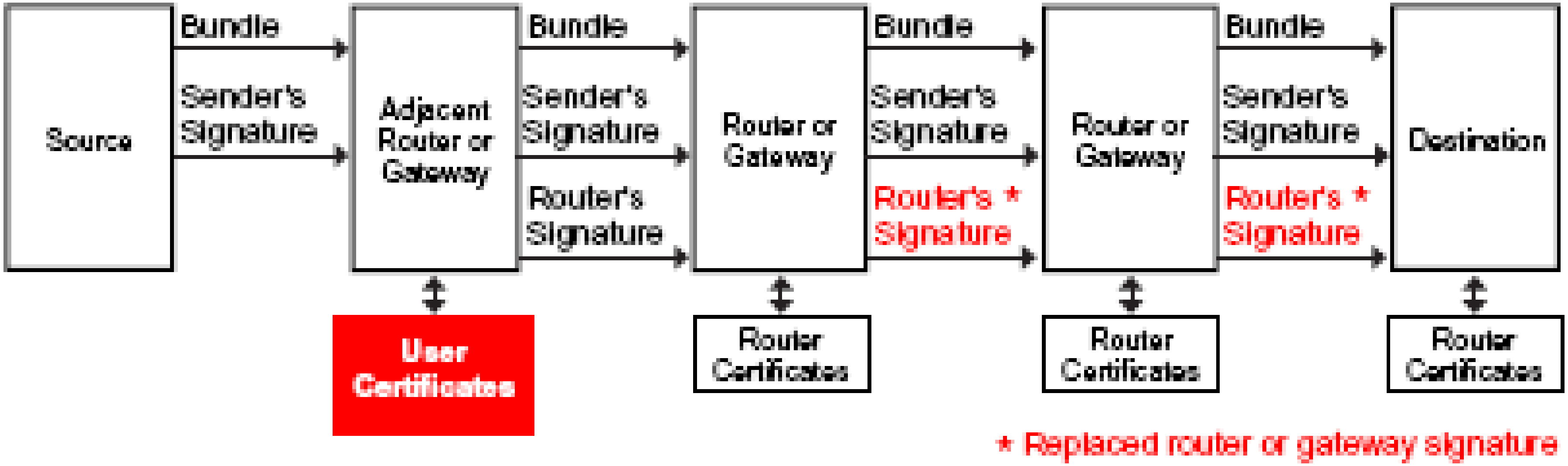


Node	IPN Regions	Node Names
Source	earth.sol.int	{earth.sol.int, src.jpl.nasa.gov:6769}
Earth Gateway	earth.sol.int ipn.sol.int	{earth.sol.int, ipngw1.jpl.nasa.gov:6769} {ipn.sol.int, ipngw1.jpl.nasa.gov}
Mars Gateway	ipn.sol.int mars.sol.int	{ipn.sol.int, ipngw2.nasa.mars.org} {mars.sol.int, ipngw2.nasa.mars.org:6769}
Destination	mars.sol.int	{mars.sol.int, dst.jpl.nasa.gov:6769}

Security Concepts

- In DTNs the following authentications occur:
  - User identity
  - Message integrity **AND**
  - Forwarding nodes, both routers and gateways
- In DTNs both users and forwarding nodes have key pairs and certificates
  - Key pairs include both public and private keys
  - Certificates, issued by a Certificate Authority (CA) is used to confirm the user's identity
    - Contains a confirmed copy of the user's public key
    - Also contains the CoS for the user
- Senders sign bundles using the private key
  - Receivers confirm authenticity of the sender, integrity of the message and sender CoS rights

Security Steps



In Conclusion

- This is an area with great potential for research, graduate theses, etc.
- Simulations of various DTN architectures
  - Requires some access to traffic loading patterns and projections
  - Routing algorithms
  - Scheduling algorithms
- Potential for collaboration with other organizations
  - NASA/JPL
  - DTNRG
  - Others

References

1. Consultative Committee for Space Data Systems, NASA, CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1, Blue Book, September 2015
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5. Fall, Kevin, A Delay-Tolerant Network Architecture for Challenged Internets, SIGCOMM, 03, August 25-29, 2003, Karlsruhe, Germany
6. Interplanetary Internet (IPN): Architectural Definition, Cerf, V., Burleigh, S., Hooke, A., Torgerson, L. etal, May 2001, Jet Propulsion Laboratory, Pasadena, Ca.

Internet Sites

1. The Internet Research Task Force's Delay-Tolerant Networking Research Group (DTNRG): http://www.dtnrg.org
2. The Interplanetary (IPN) Internet Project: http://www.ipnsig.org
3. Current draft standards at: https://datatracker.ietf.org/doc/search/?name=DTN&sort=&rfcs=on&activedrafts=on