Delay- and Disruption-Tolerant Networks (DTNs)

A Primer

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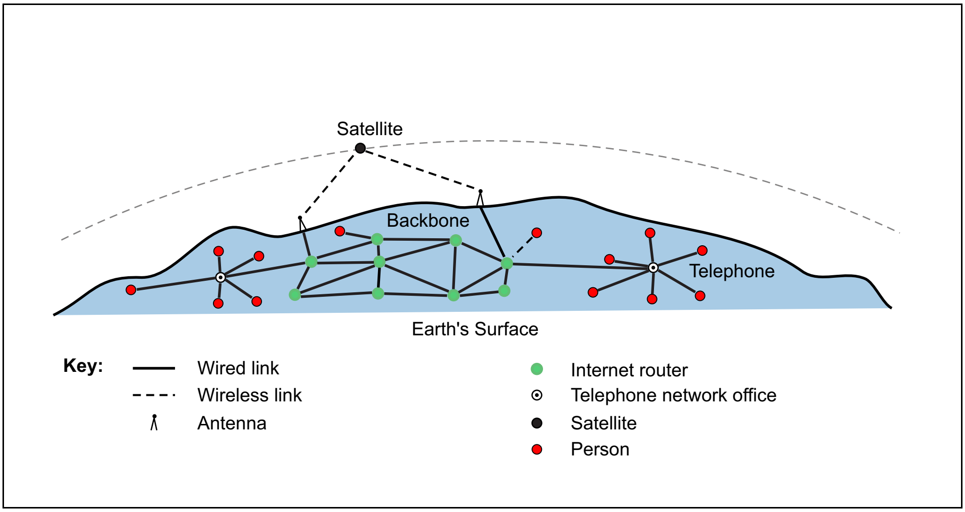
Today’s Internet

The Internet has been a great success at interconnecting communication devices across the Earth. It has done this by using a homogeneous set of communication protocols, called the *TCP/IP protocol suite*. All devices on the hundreds of thousands of networks that make up the Internet use these protocols for routing data and insuring the reliability of message exchanges.

Connectivity on the Internet relies primarily on wired links, including the wired telephone network, although wireless technologies such as satellite and short-range mobile links are also an essential part of the network. These links, as used on the Internet, are continuously connected in end-to-end, low-delay paths between sources and destinations. They have low error rates and relatively symmetric bidirectional data rates.



Evolving Wireless Networks Outside the Internet

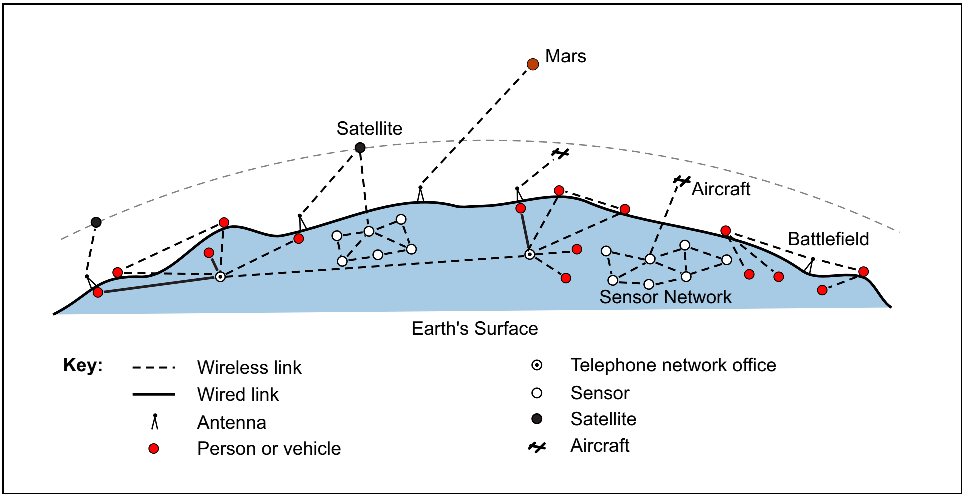
Communication outside of the Internet—where power-limited wireless communications are developing—is done on independent networks, each supporting specialized communication protocols. Most of these networks are mutually incompatible—each is good at passing messages *within* its network, but not able to exchange messages *between* networks.

The nodes of each network communicate among themselves using the same set of communication protocols. Each network also has communication characteristics that are relatively homogeneous—for example, link delay, link connectivity, data-rate asymmetry, error rates, addressing and reliability mechanisms, quality-of-service provisions, and trust boundaries. Unlike the Internet, the evolving wireless networks support long and variable delays, arbitrarily long periods of link disconnection, high error rates, and large bidirectional data-rate asymmetries.

Examples of wireless networks outside of the Internet include:

- Civilian networks on Earth that connect mobile wireless devices, such as networks for intelligent highways, and remote environmental and animal-movement outposts.
- Wireless military battlefield networks connecting troops, aircraft, satellites, and sensors on land and in water.
- Outer-space networks, such as the InterPlaNetary (IPN) Internet project, described at *http://www.ipnsig.org*.

Spanning two networks requires a protocol agent that can translate between network protocols and act as a buffer for mismatched network delays.



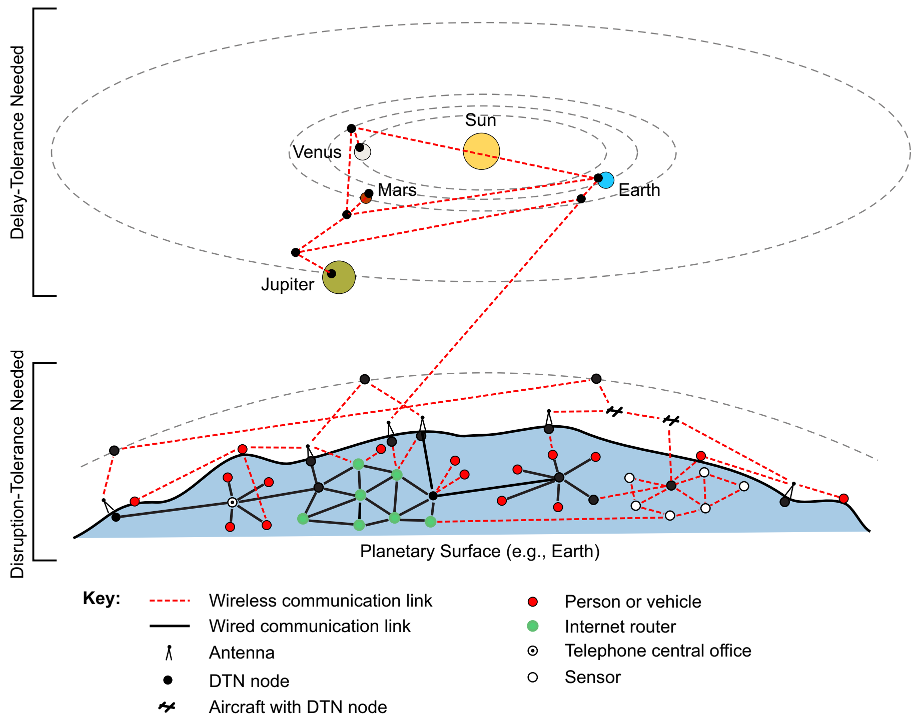
The Concept of a Delay- and Disruption-Tolerant Network (DTN)

A DTN is a network of smaller networks. It is an overlay on top of special-purpose networks, including the Internet.

DTNs support interoperability of other networks by accommodating long disruptions and delays between and within those networks, and by translating between the communication protocols of those networks. In providing these functions, DTNs accommodate the mobility and limited power of evolving wireless communication devices.

DTNs were originally developed for interplanetary use, where the speed of light can seem slow and delay-tolerance is the greatest need. However, DTNs may have far more diverse applications on Earth, where disruption-tolerance is the greatest need. The potential Earth applications span a broad range of commercial, scientific, military, and public-service applications.

DTNs can accommodate many kinds of wireless technologies, including radio frequency (RF), ultra-wide band (UWB), free-space optical, and acoustic (sonar or ultrasonic) technologies.



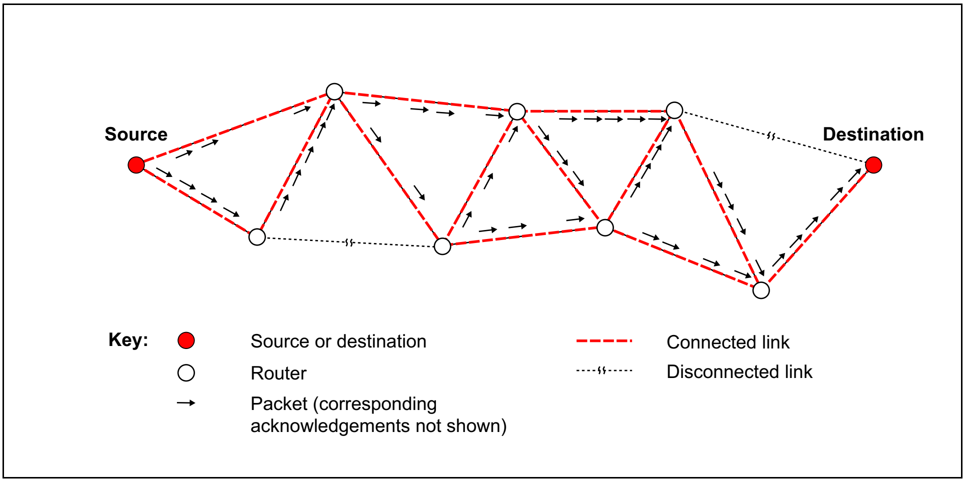
Today's Internet—Packet-Switching

Communication on the Internet is based on *packet-switching*. *Packets* are pieces of a complete block of user data (e.g., pieces of an email message or a web page) that travel independently from source to destination through a network of links connected by routers. Routers switch the direction in which the packets move. The source, destination, and routers are collectively called *nodes*.

Each packet that makes up a message can take a different path through the network of routers. If one link is disconnected, routers redirect the packets to use an alternate link. Packets contain both application-program user data (the payload part) and a header (the control part). The header contains a destination address and other information that determines how the packet is switched from one router to another. The packets in a given message may arrive out of order, but the destination's transport mechanism reassembles them in correct order.

The usability of the Internet depends on some important assumptions:

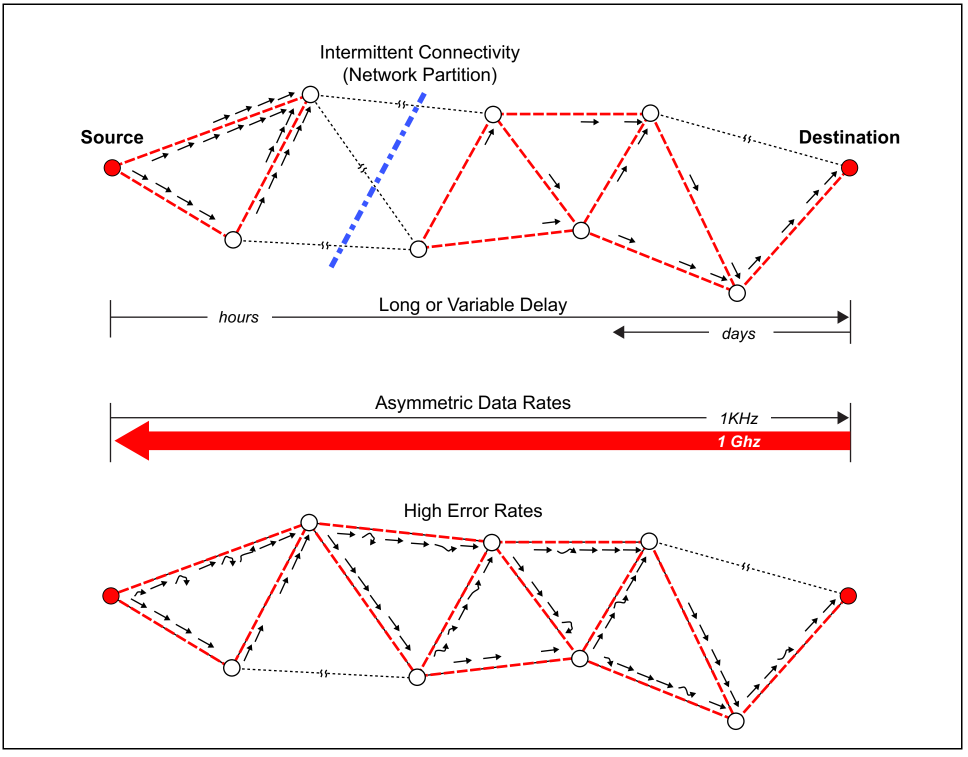
- *Continuous, Bidirectional End-to-End Path:* A continuously available bidirectional connection between source and destination to support end-to-end interaction.
- *Short Round-Trips:* Small and relatively consistent network delay—milliseconds, not hours or days—in sending data packets and receiving the corresponding acknowledgement packets.
- *Symmetric Data Rates:* Relatively consistent data rates in both directions between source and destination.
- *Low Error Rates:* Relatively little loss or corruption of data on each link.



Why a Delay- and Disruption-Tolerant Network (DTN)?

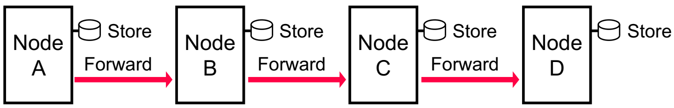
Many evolving and potential communication environments do not conform to the Internet's underlying assumptions (page 6). These environments are characterized by:

- *Intermittent Connectivity:* In the absence of an end-to-end path between source and destination—called *network partitioning*—communication using the TCP/IP protocols does not work. Other protocols are required.
- *Long or Variable Delay:* In addition to intermittent connectivity, long propagation delays between nodes and variable queuing delays at nodes contribute to end-to-end path delays that can defeat Internet protocols and applications that rely on quick return of acknowledgements or data.
- *Asymmetric Data Rates:* The Internet supports moderate asymmetries of bidirectional data rate for users with cable TV or asymmetric DSL service. But if asymmetries are large, they defeat conversational protocols (page 7).
- *High Error Rates:* Bit errors on links require correction (which requires more bits and more processing) or retransmission of the entire packet (which results in more network traffic). For a given link-error rate, fewer retransmissions are needed for hop-by-hop retransmission than for Internet-type end-to-end retransmission (linear increase vs. exponential increase, per hop).



Store-And-Forward Message Switching

DTNs overcome the problems associated with intermittent connectivity, long or variable delay, asymmetric data rates, and high error rates by using *store-and-forward message switching*. This is a very old method, used by pony-express and postal systems since ancient times. Whole messages (entire blocks of application-program user data)—or pieces (fragments) of such messages—are moved (forwarded) from a storage place on one node (switch intersection) to a storage place on another node, along a path that *eventually* reaches the destination.



Store-and-forwarding methods are also used in today's voicemail and email systems, but these systems are not node-to-node relays (as shown above) but rather star relays; both the source and destination independently contact a central storage device at the center of the links.

The storage places (such as hard disk) can hold messages indefinitely. They are called *persistent storage*, as opposed to very short-term storage provided by memory chips and buffers. Internet routers use memory chips and buffers to store (queue) incoming packets for a few milliseconds while they are waiting for their next-hop routing-table lookup and an available outgoing router port.

DTN routers need persistent storage for their queues for one or more of the following reasons:

- A communication link to the next hop may not be available for a long time.
- One node in a communicating pair may send or receive data much faster or more reliably than the other node.
- A message, once transmitted, may need to be retransmitted if an error occurs at an upstream (toward the destination) node, or if an upstream node declines acceptance of a forwarded message.

By moving whole messages (or fragments thereof) in a single transfer, the message-switching technique provides network nodes with immediate knowledge of the size of messages, and therefore the requirements for intermediate storage space and retransmission bandwidth.

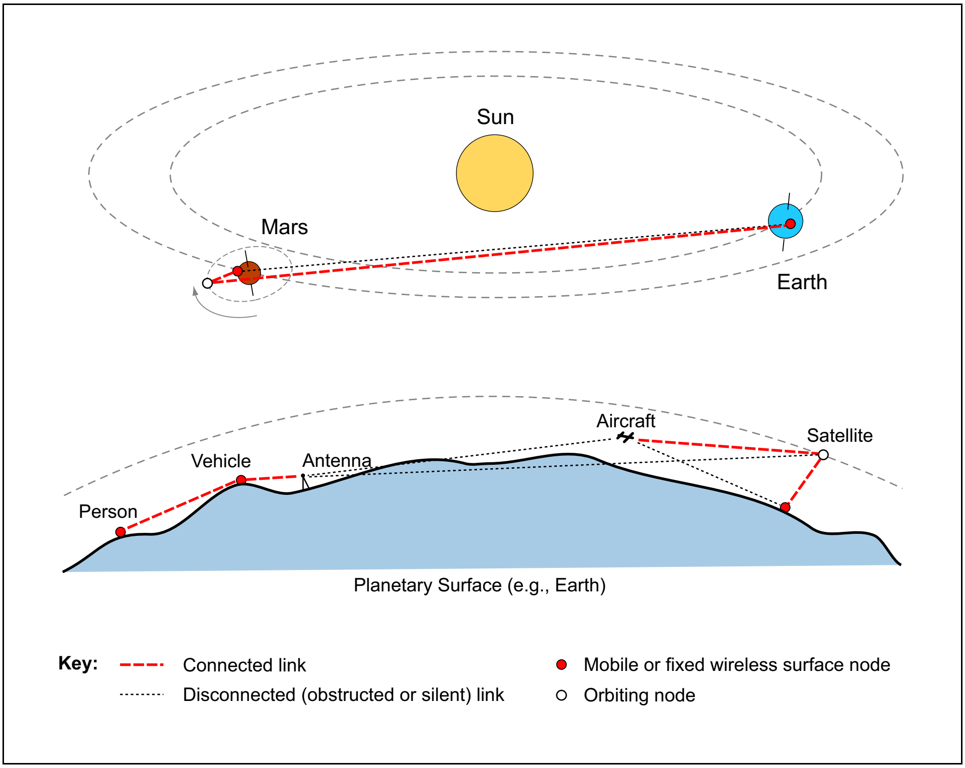
Intermittent Connectivity

A growing number of communicating devices are in motion and operate on limited power. This is true in interplanetary space and is becoming more common on Earth among mobile wireless communication devices, such as cell phones.

When communicating nodes are in motion, links can be obstructed by intervening bodies. When nodes must conserve power or preserve secrecy, links are shut down. These events cause *intermittent connectivity*. When no path exists to connect a source with a destination, a *network partition* is said to occur.

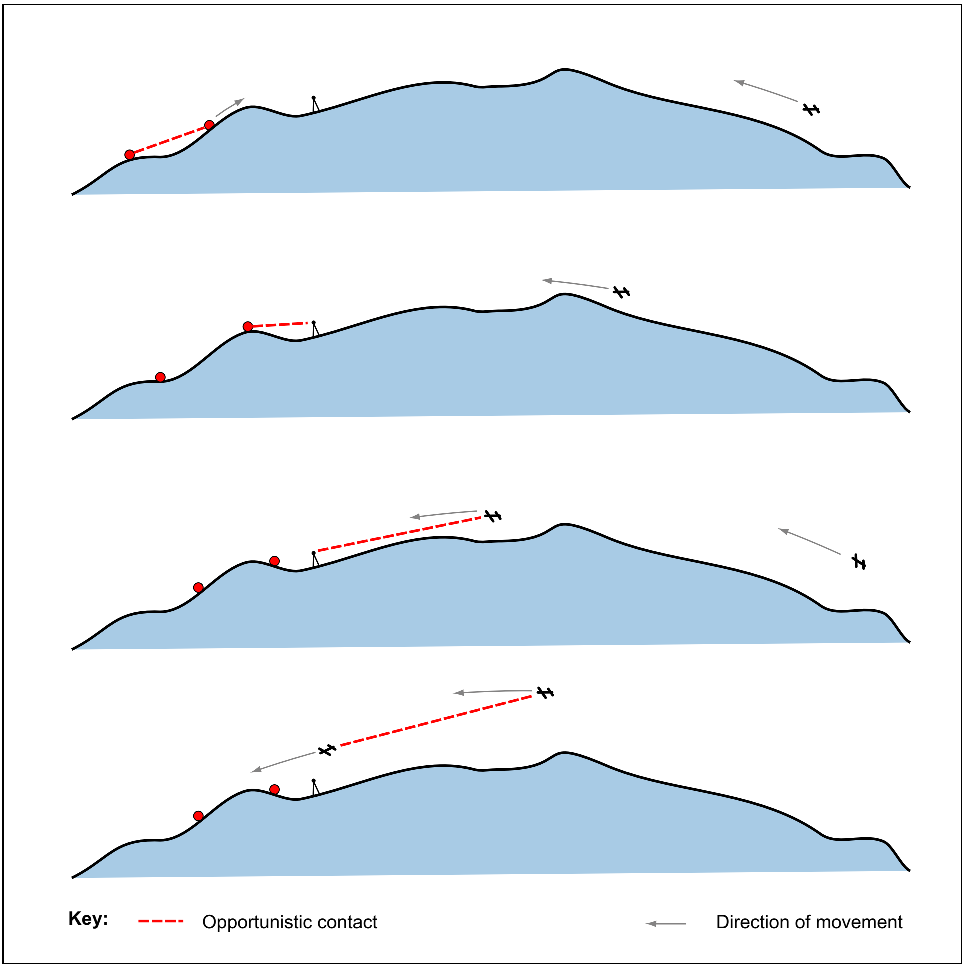
On the Internet, intermittent connectivity causes loss of data. Packets that cannot be immediately forwarded are usually dropped (discarded), and the TCP protocol may retransmit them with slower retransmission timing. If packet-dropping is too severe, TCP eventually ends the session, which can cause applications to fail.

DTNs, by contrast, support communication between intermittently connected nodes by isolating delay and disruptions with a store-and-forward technique (page 8). The intermittent connectivity may be opportunistic (page 10) or scheduled (page 11).



Network nodes may need to communicate during *opportunistic contacts*, in which a sender and receiver make contact at an unscheduled time. Moving people, vehicles, aircraft, or satellites may make contact and exchange information when they happen to be within line-of-sight and close enough to communicate using their available (often limited) power.

All of us use opportunistic contacts for communication: when we happen, by chance, to meet certain people with whom we wish to talk, we begin a conversation. This same model can apply to electronic communication. For example, wireless mobile devices such as cell phones can be designed to send or receive information when certain people carrying the mobile device come within communication range, or when the mobile device is carried past an information kiosk.

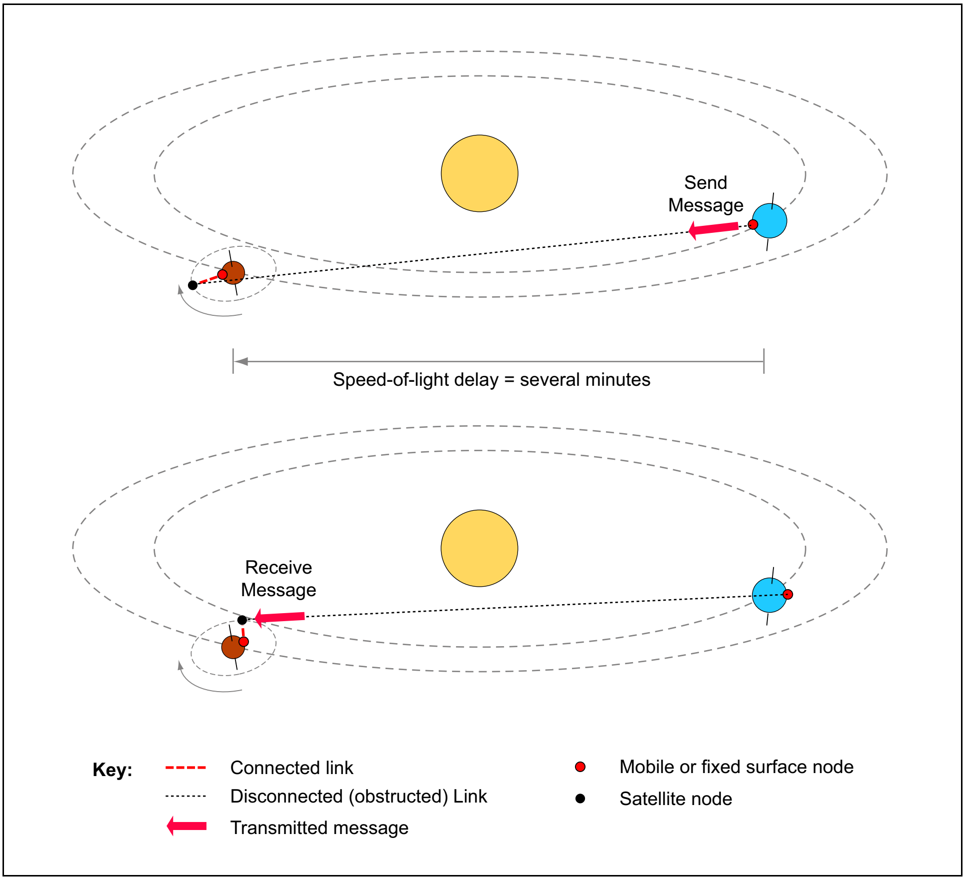


Scheduled Contacts

In space, almost everything is in motion and speed-of-light delays are significant (tens of minutes within our solar system). Potentially communicating nodes move along predictable orbital paths, so they can predict or receive time schedules of their future positions and thereby arrange their future communication sessions.

Scheduled contacts may involve message-sending between nodes that are not in direct contact, as shown in the figure below. They may also involve storing information until it can be forwarded, or until the receiving application can catch up with the sender's data rate.

Scheduled contacts require time-synchronization throughout the DTN.



Potential Applications of DTN Technology

The DTN store-and-forward message switching architecture is a generalization of work originally conceived to support the InterPlaNetary Internet (IPN). The primary goals are interoperability across network environments, and reliability capable of surviving hardware (network) and software (protocol) failures.

Although DTNs were originally conceived for interplanetary use, they may have a far greater number of applications on Earth. Here is a short summary of the possible applications:

- Space Agencies: International Space Station communication (currently operational for research), interplanetary communication, future space-debris monitoring.
- Military and Intelligence: Mobile ad-hoc networks (MANETs) for wireless communication and monitoring, cargo tracking, search and rescue communication, unmanned aerial vehicle (UAV) communication and control.
- Commercial: Cargo and vehicle tracking (by road, rail, sea, and air), in-store and in-warehouse asset tracking, data transactions (e.g., financial, reservations), agricultural crop monitoring, processing-plant monitoring, communication in underground mines.
- Public Service and Safety: Security and disaster communication, search and rescue communication, humanitarian relief monitoring, smart-city event-response, smart transportation networks, smart electric-power networks, global airport-traffic control, infrastructure-integrity monitoring, unmanned aerial vehicle (UAV) communication and control, remote learning.
- Personal Use: Personal monitoring and communication in wilderness and urban areas, fire-and-forget text messaging.
- Environmental Monitoring: Animal migration, soil properties and stability, atmospheric and oceanographic conditions, seismological events.
- Engineering and Scientific Research: Network subject-matter experts, academic research by faculty and students.