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Delay-tolerant networking

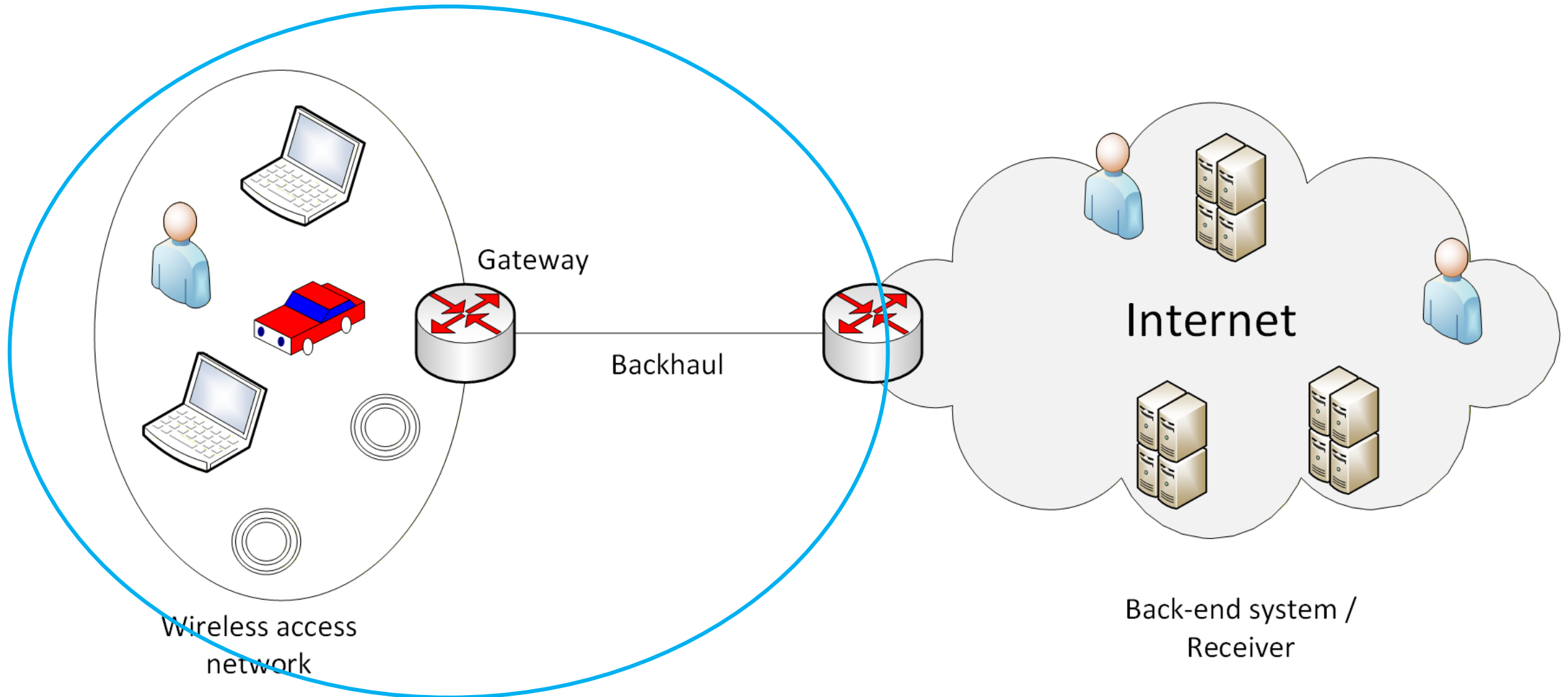
MARIA KIHLM



Literature

- Forrest Warthman, "Delay- and Disruption- tolerant Networks (DTNs), a Tutorial", Report from the InterPlanetary Networking Special Interest Group (IPNSIG), 2015. Accessed from: <http://ipnsig.org/introducing-delay-disruption-tolerant-networking-dtn/>
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Today's lecture: Delay- and Disruption- tolerant Networks (DTNs)



Today's scenario: Reindeer herding

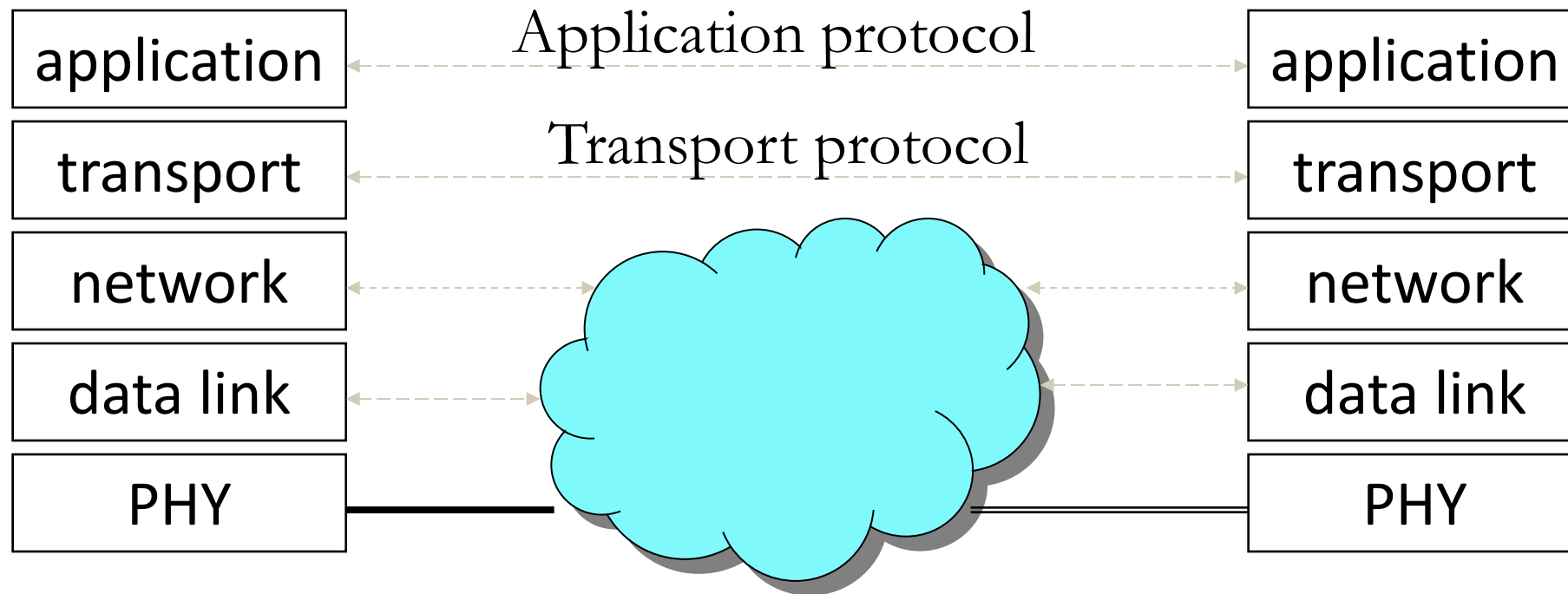
You have been asked to help a Sami community situated in an area of the most northern parts of Sweden (also called Sápmi). They would like to have a tracking solution for their reindeer herds. Positioning data should be collected about the reindeers' movements and sent to a cloud server. Due to the large distances, the positioning data do not need to be exact. There can be an acceptable error in the positioning of about 1 km.

Also, your solution should enable the herders to have access to some basic Internet applications, as sending emails and web browsing, at suitable places. In addition, the reindeer herders should be able to monitor the reindeers through an app on their cell phone or laptop when they have Internet access.

Note: Even if Sweden has good cellular network coverage, there are large parts of Sápmi with very bad connectivity conditions. Your solution must reflect this.

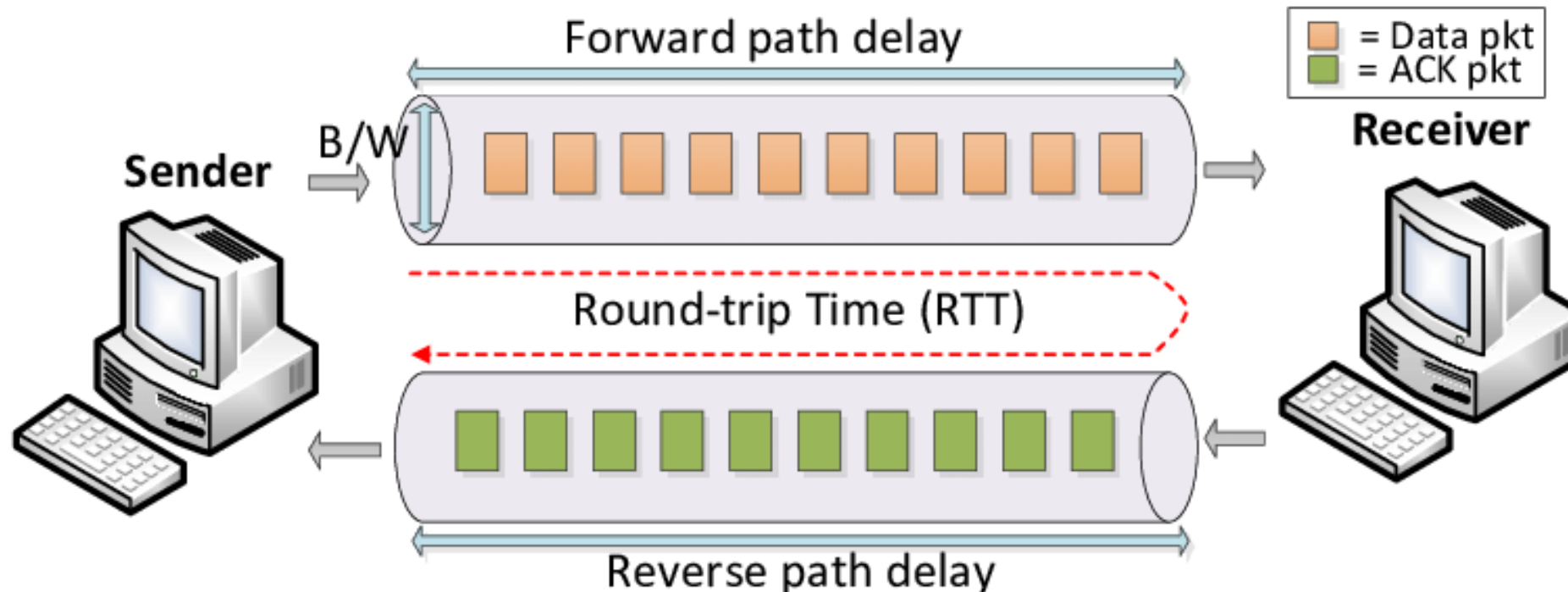


Recap: Traditional Internet protocols



Recap: Internet protocols are “conversational”

Internet protocols assume that there is a continuous flow of messages between a sender and receiver.



Some assumptions so far:

- **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.

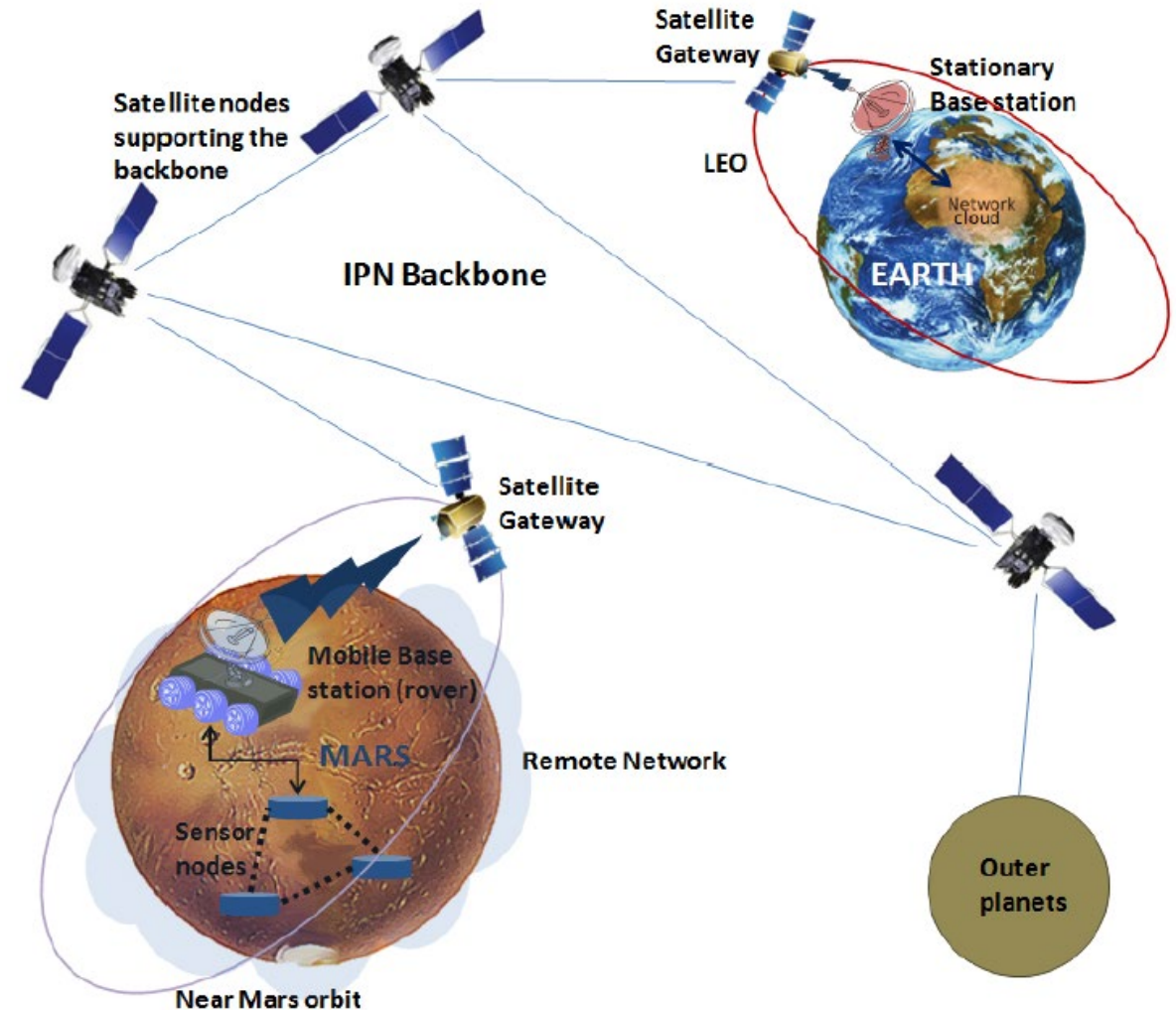
What if you instead have:

- **Intermittent Connectivity:** The absence of an end-to-end path between source and destination is called network partitioning.
 - In such cases, communication using the TCP/IP protocols does not work.
- **Long or Variable Delay:** Long delays between nodes contribute to end-to-end path delays.
 - Can defeat Internet protocols and applications that rely on quick return of acknowledgements or data.
- **Asymmetric Data Rates:** The data rate in one direction is much higher than the data rate in the other direction.
 - Can defeat conversational protocols like TCP.
- **High Error Rates:** High probability of errors mean high probability of retransmissions.
 - For a given link-error rate, fewer retransmissions are needed for hop-by-hop retransmission than for Internet-type end-to-end retransmission (TCP).

Example: Interplanetary networks

Interplanetary networks and outer space networks are still most visions.

But, there are large projects and organizations that try to solve the technical challenges, for example NASA, ESA, CNSA, and SpaceX.



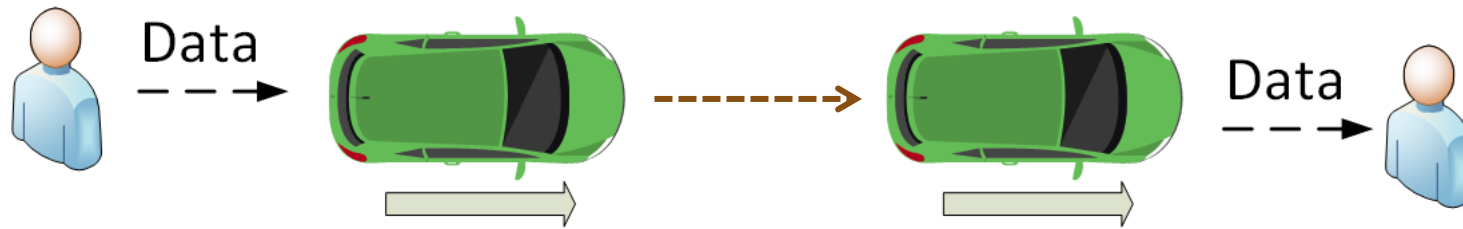
Delay- and Disruption-Tolerant Networks (DTNs)

- DTN is a **technology (or concept)** for data communication with long delays and much disruptions.
- The DTN technology was originally developed for **interplanetary networks**, where the speed of light can seem slow, and delay-tolerance is the greatest need.
- However, the DTN technology has far more diverse applications on Earth, where disruption-tolerance is the greatest need.
 - For example, **sensor networks**.
- DTNs accommodating **long disruptions and delays** within and between networks
 - A DTN is an **overlay network on the application layer**, where specific nodes act as so called **DTN routers**.
 - The DTN router is responsible for the DTN communication to another DTN router.

Requirement for DTNs

There is one hard requirement for deploying a DTN solution:

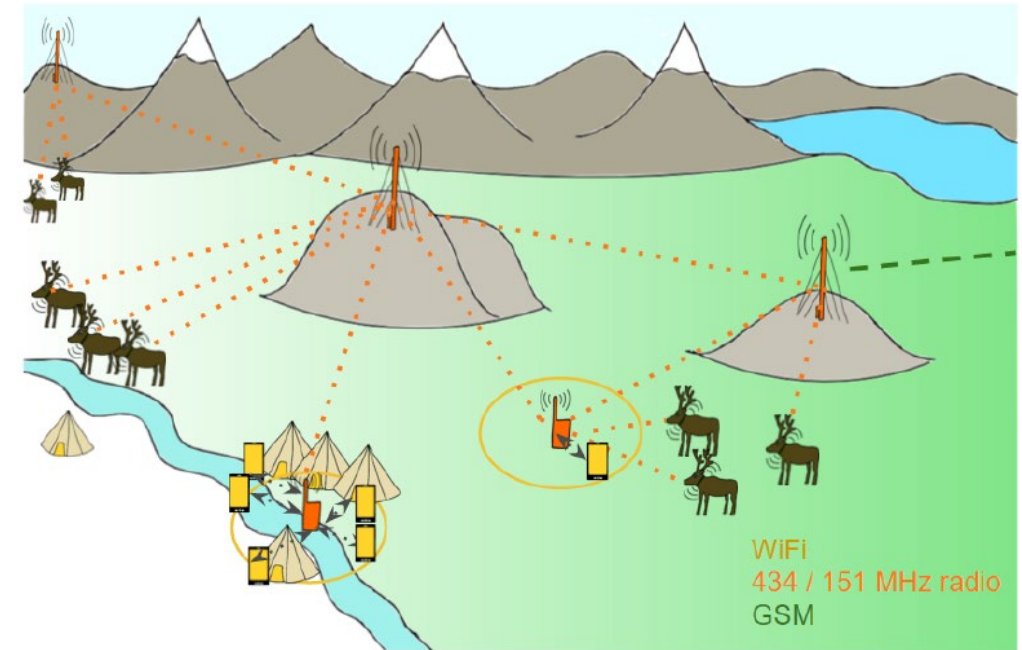
The network system must include moving nodes that can carry information towards a next node, and thereby creating new communication links on the way.



DTN application: Sensor networks

Various scenarios based on environmental or animal monitoring can be solved using DTN architectures. A scenario can use DTN if:

- The data is delay-tolerant and some errors are acceptable.
- Limited data rates.
- Long distances or bad connectivity conditions.
- There are moving nodes that can transport data towards better connectivity.



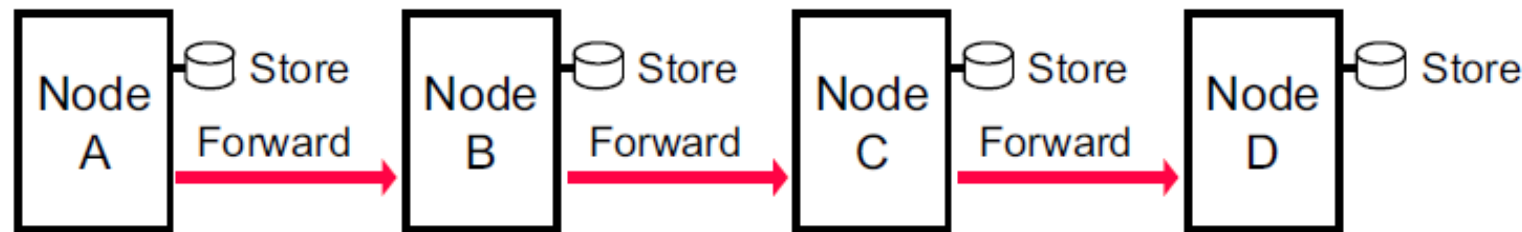
DTN Solution:

Store-And-Forward Message Switching

In Store-and-forward message switching, messages are moved (forwarded) from a storage place on one node to a storage place on another node, along a path that eventually reaches the destination.

The store-and-forward mechanism is implemented on the **Application layer**.

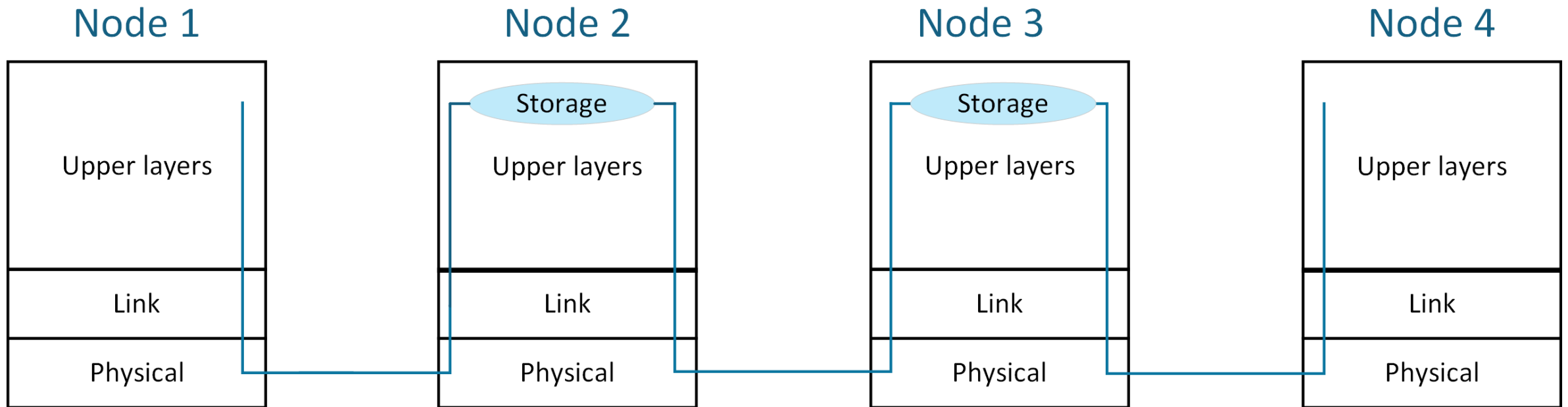
A network system that deploys store-and-forward message switching is called a Delay- and Disruption Tolerant Network (DTN).



Store-and-forward - illustration

In each node, the message is stored and then forwarded when the next link is available.

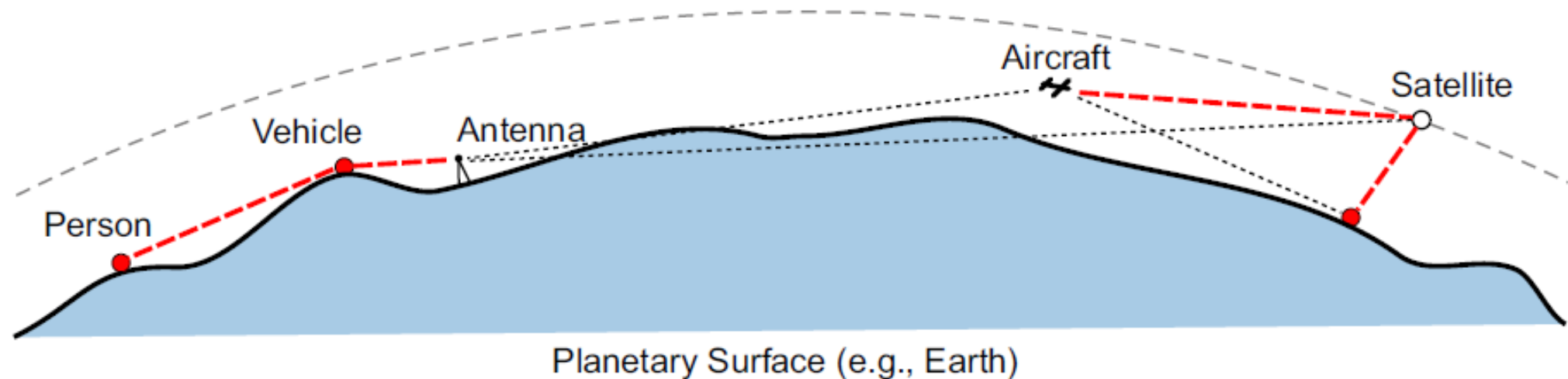
- Different links can have different link layer protocols.



Motivations

Store-and-forward message switching is good when:

- A communication link to the next hop may not be available for a long time.
- The full end-to-end path is not reliable (thereby excluding end-to-end protocols as TCP), but some of the point-to-point links on the path have better reliability.

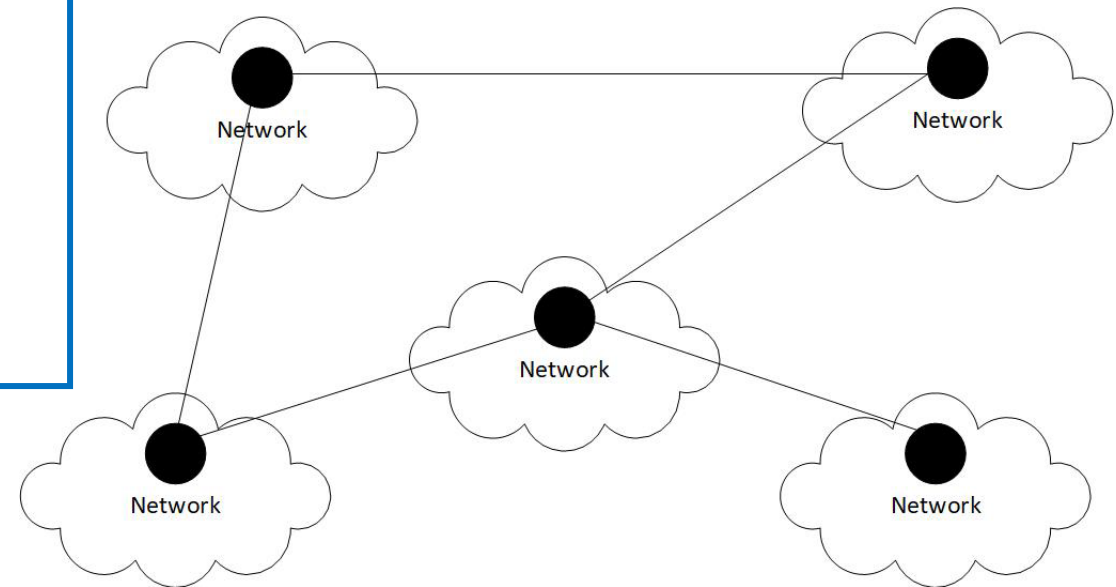


General DTN architectures

DTNs are deployed as an overlay network on the **application layer**.

- **Internet systems (multiple networks):** The **DTN routers** (one in each network in the figure) participate in the DTN and send data between each other. The DTN routers (also called **DTN nodes**) communicate between themselves using simple sessions.

- **Wireless network (one network):** In a DTN consisting of only one network, some or several nodes in the network act as DTN nodes, and send data between each other using the store-and-forward principle.



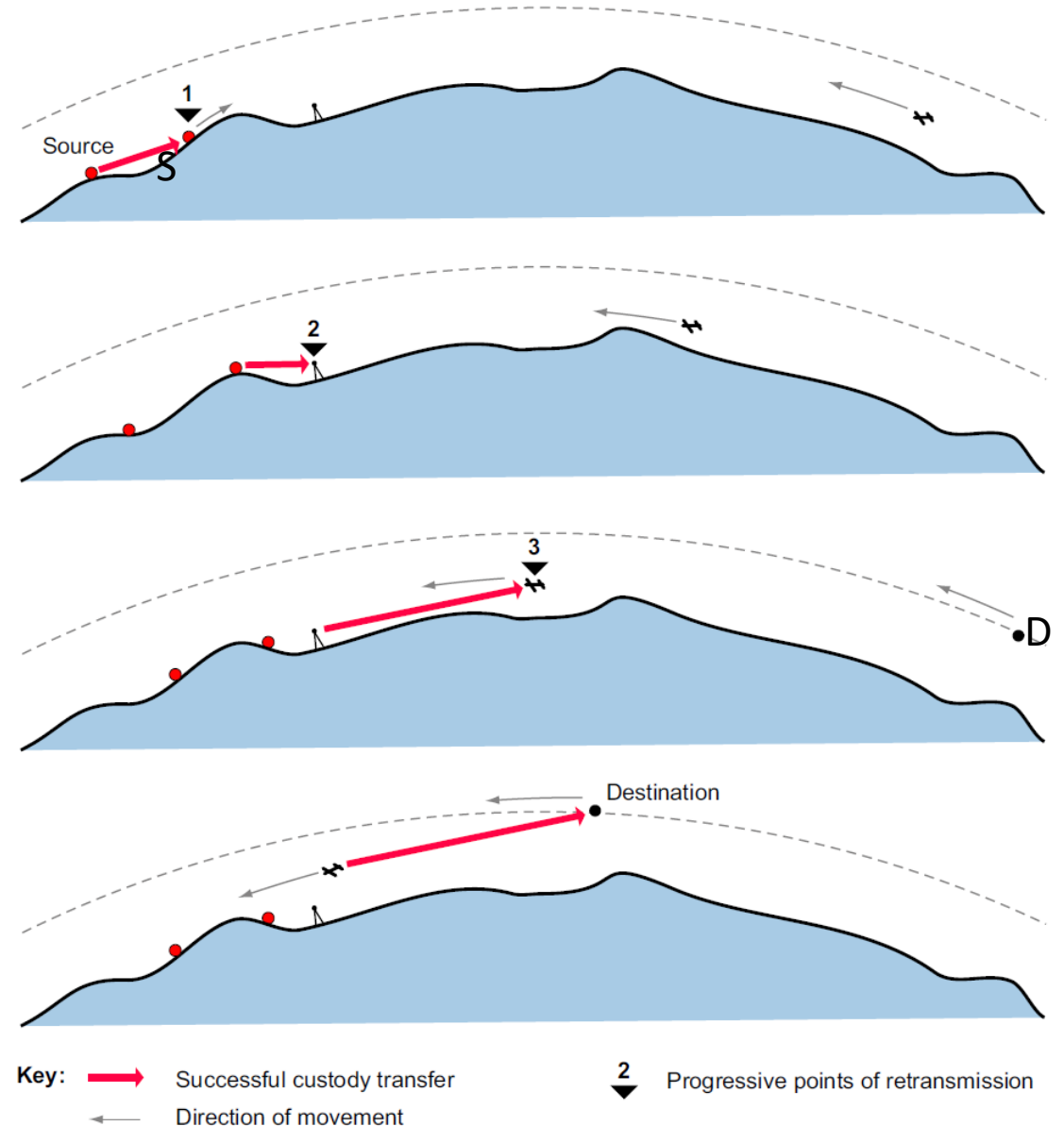
Example of Data transfer with DTN

1: **S** want to send data to **D** (a satellite/planet that is currently outside the figure). S sends the data to the closest **DTN router 1**.

2: Some time later, the next **DTN router 2** is in range, and the data is transferred to this router.

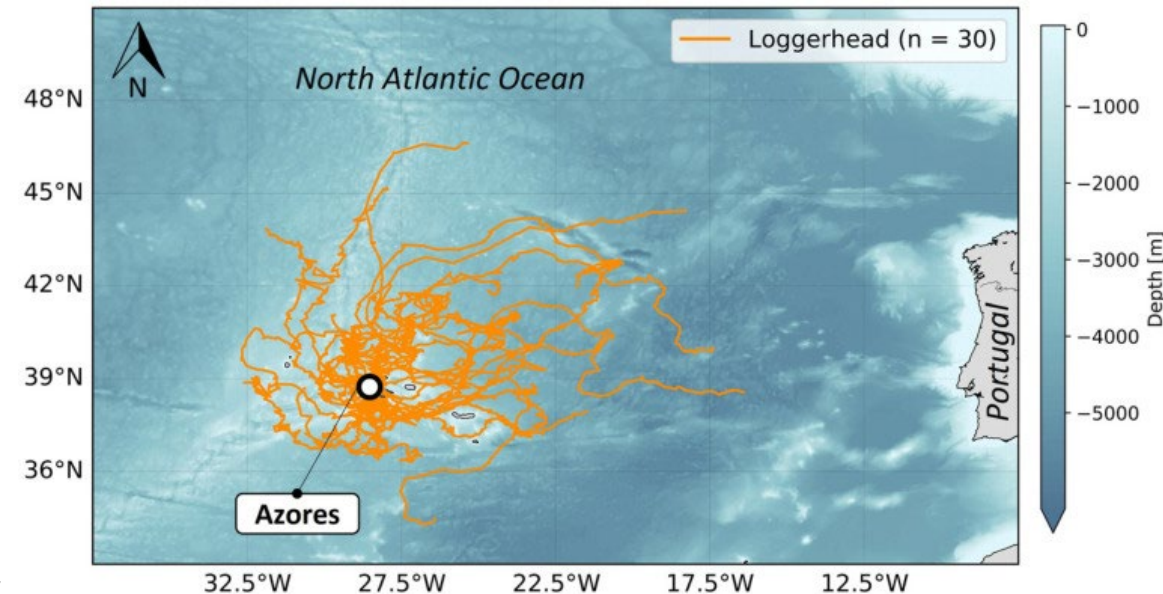
3. Later, **DTN router 3** is in range, and receives the data.

4. Finally, D has come in range of DTN router 3, and can receive the data.



DTN example: Tracking of sea turtles

- Micro-satellite tags for Argos, the smallest one only 2.5 grams, were placed on 224 juvenile turtles.
- The **tags stored data on the way**, for example about the sea turtle's current depth under sea level.
- The **tags can detect when the antenna is clear of the water**.
- When the antenna is clear of water, **the tag transmits its stored data to the Argos satellites**.



Multi-hop routing (Data dissemination) in DTNs

Two general routing principles:

- Opportunistic routing
- Scheduled routing

One technique that can be used to maximize the probability of a message being successfully transferred is to **replicate** a message in several copies in hopes that one will succeed in reaching its destination.

Opportunistic routing

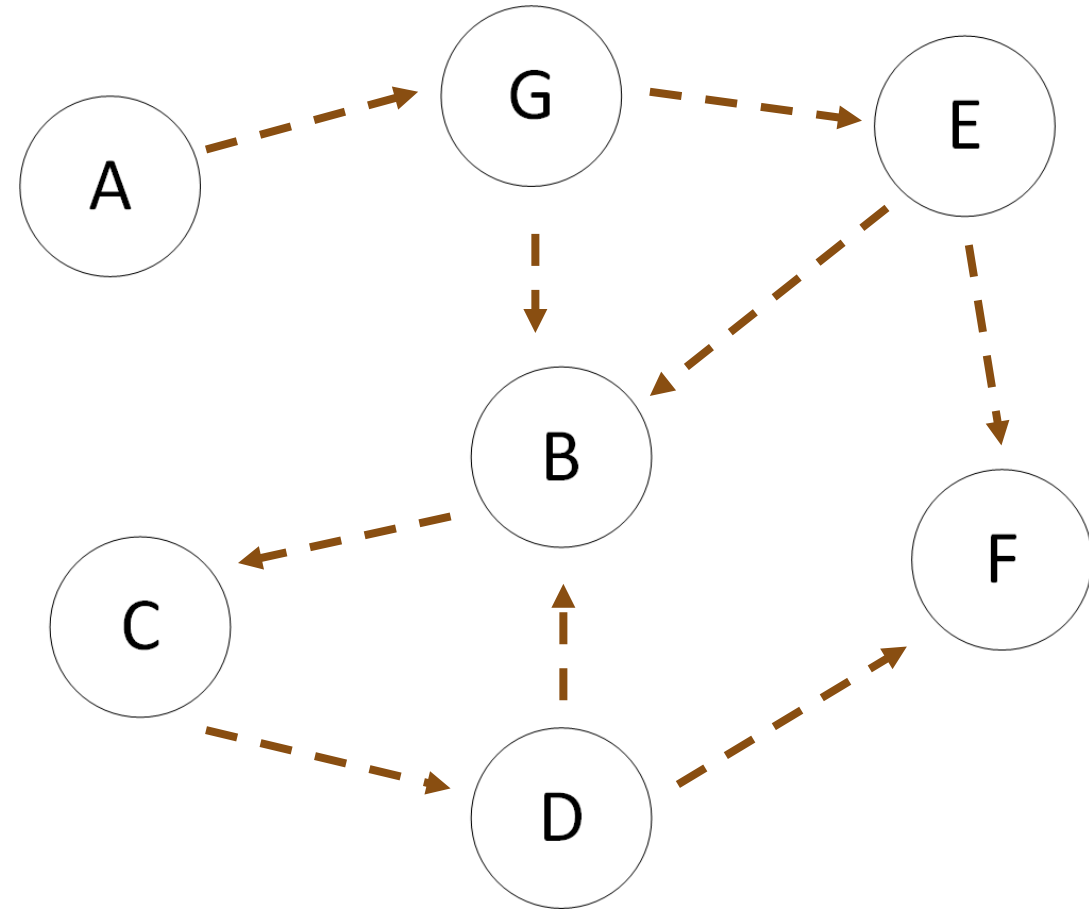
- Basically creates an **ad-hoc** network architecture.
- Nodes communicate during so called opportunistic contacts, which means that a **sender and receiver make contact when they are within radio range**.
- Moving people, vehicles, aircraft, or satellites may make contact and exchange information when they happen to be within line-of-sight and **close enough to communicate** using their available (often limited) power.
- Opportunistic routing requires a communication technology that allows for **ad-hoc connections**, or at least connections that can be set-up automatically.

Example: Gossiping / Epidemic routing

- Gossiping (also called Epidemic routing) is an **opportunistic multi-hop routing scheme** that can be used in DTN solutions.
- Gossiping was originally developed for ad-hoc networks where the connectivity is sparse and dynamic, which means that nodes not always have neighbor nodes to forward data to.
- There are numerous Gossip protocols.
 - A Gossip protocol can be developed for either unicast, multicast, geocast or broadcast data transfer.
 - Data can be forwarded to one or several neighbors.
- **There are no guarantees that the message will be received by the intended destination node.**

Gossiping, illustration

- Assume that A wants to send a data message to F.
- A selects one or more of its neighbors **according to some criteria** and forwards the message to these nodes.
- A receiving node (G in the figure) forwards the message to one or more of its neighbors.
- Nodes keep forward messages until some time-out, and hopefully the message reaches F.



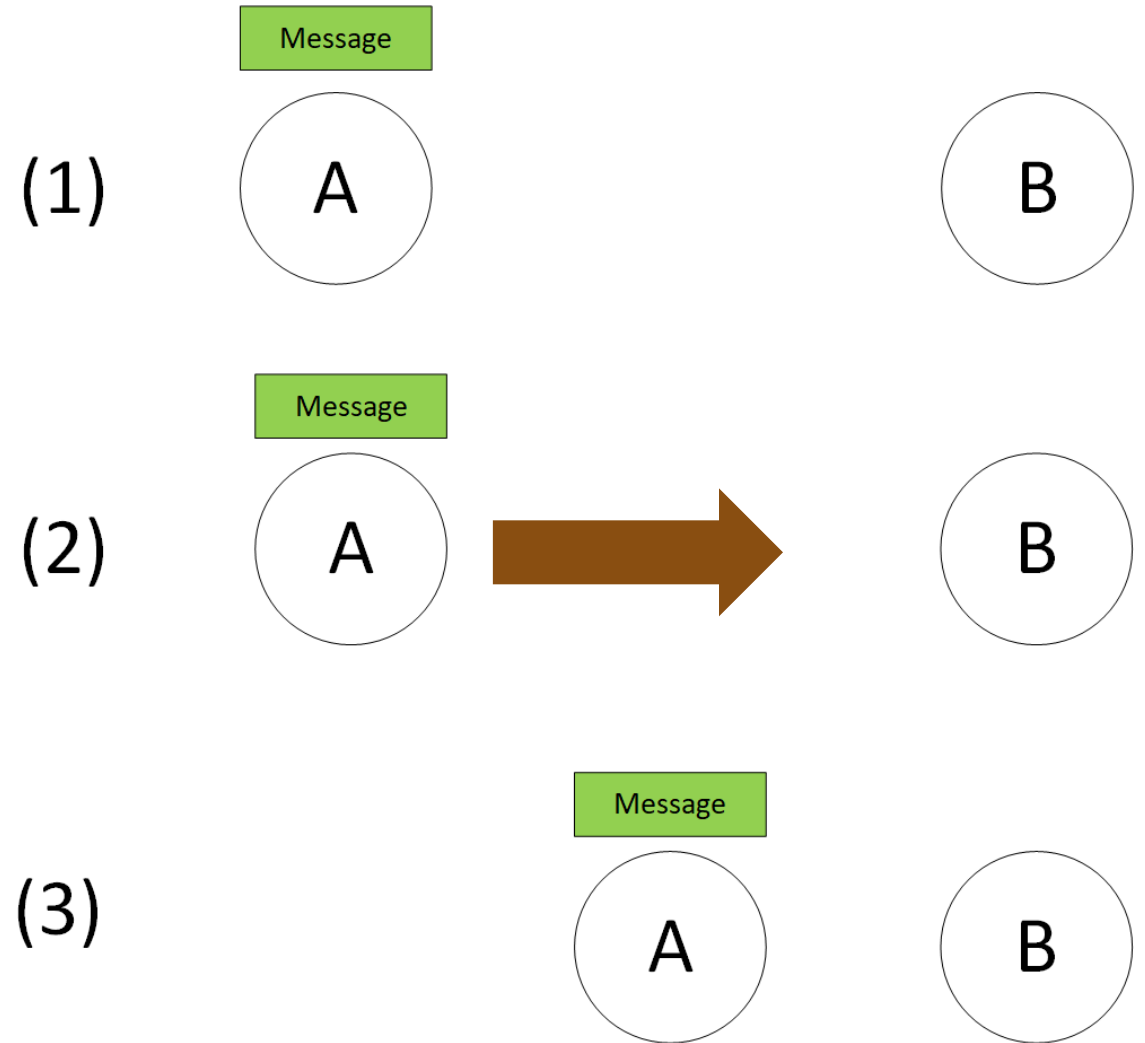
Gossiping with a DTN solution

- Nodes **stores messages they receive**, then **replicate and transmit the messages to newly discovered contacts** (until some time-out or hop-count etc).
- Using a globally unique message ID a node can determine if it has received and forwarded this message before.
- A hop count can limit the routing algorithm from causing congestion in the network by only allowing a specified number of hops from source to destination.

Gossiping with DTN, Illustration

- (1) Node A has a Message that it wants to forward.
- (2) Node A happens to move in the direction towards B.
- (3) When Node A is close to B, it can connect with B and transmit the message.

Both A and B can store the message and potentially transmit it to other nodes that they meet later.

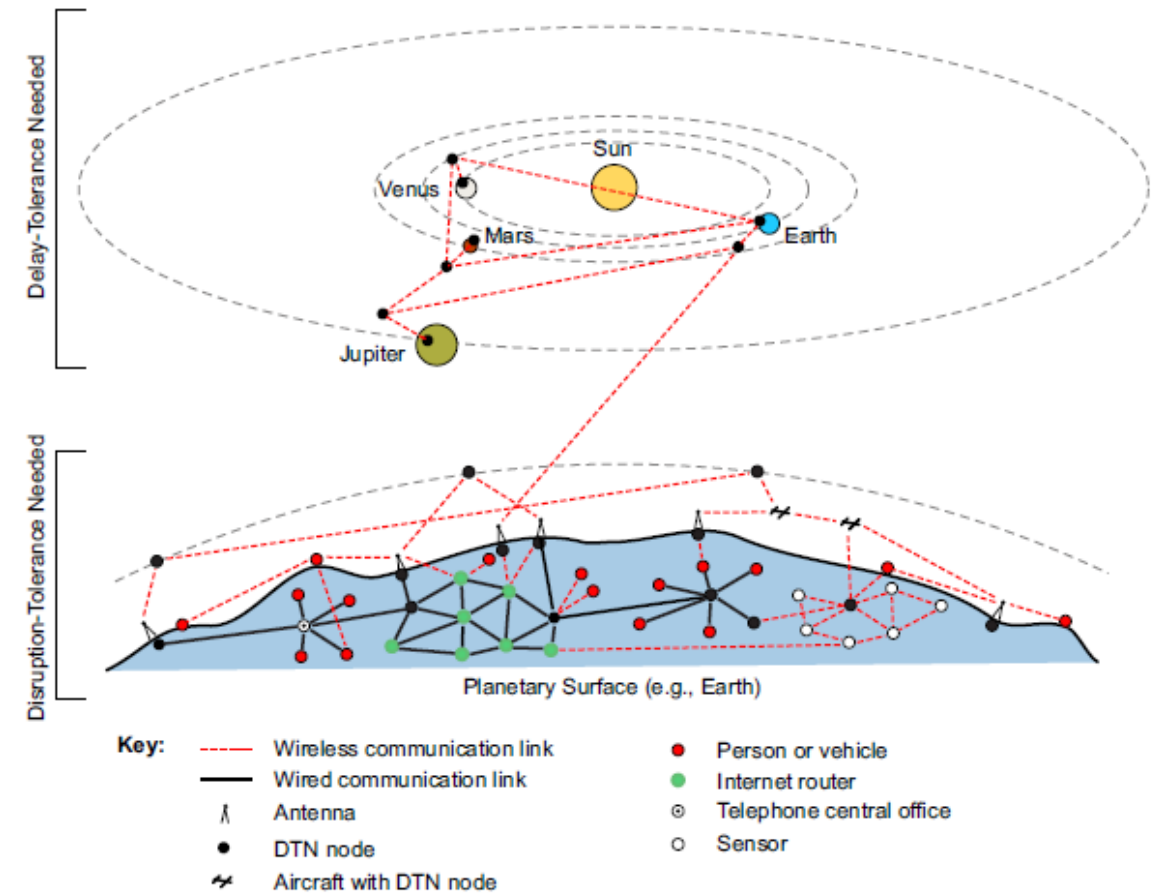


Scheduled routing

- Scheduled routing requires time-synchronization throughout the DTN.
- Communicating nodes must move along **predictable paths**, so they can predict or receive time schedules of their future positions and thereby arrange their future communication sessions.
- Scheduled routing **can be used in interplanetary networks** with very long delays and predictable orbital paths.

DTN Example: Interplanetary networks

- In an interplanetary network, there can be DTN routers placed close to planets, satellites, and earth.
- The DTNs routers communicate with each other using DTN protocols.
- Other nodes communicate with their closest DTN router if they want to send data to a node connected to another DTN router.



Reindeer herding: System design using a DTN?

You have been asked to help a Sami community situated in an area of the most northern parts of Sweden (also called Sápmi). They would like to have a tracking solution for their reindeer herds. Positioning data should be collected about the reindeers' movements and sent to a cloud server. Due to the large distances, the positioning data do not need to be exact. There can be an acceptable error in the positioning of about 1 km.

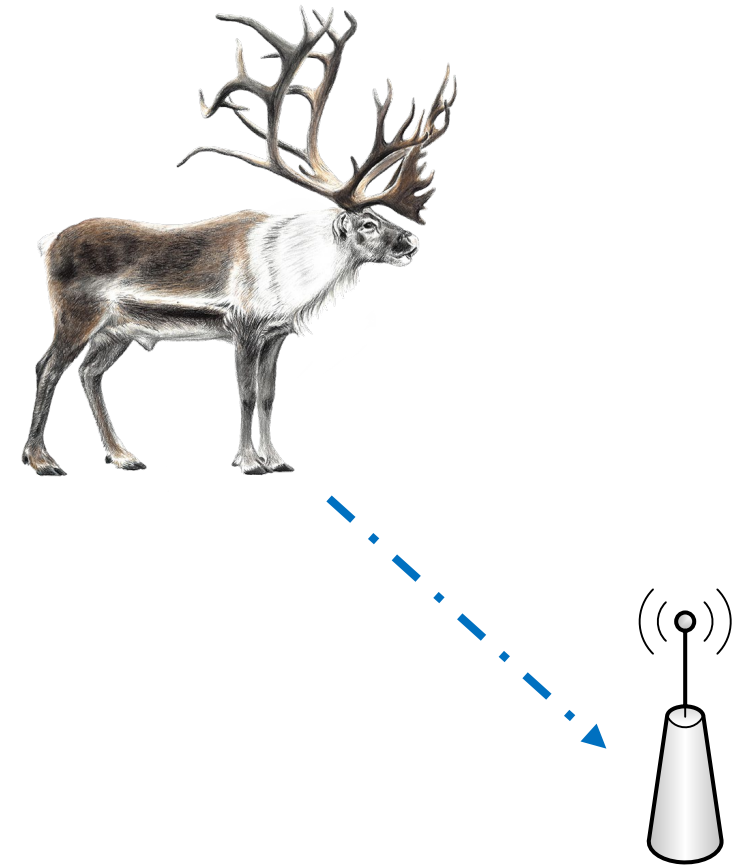
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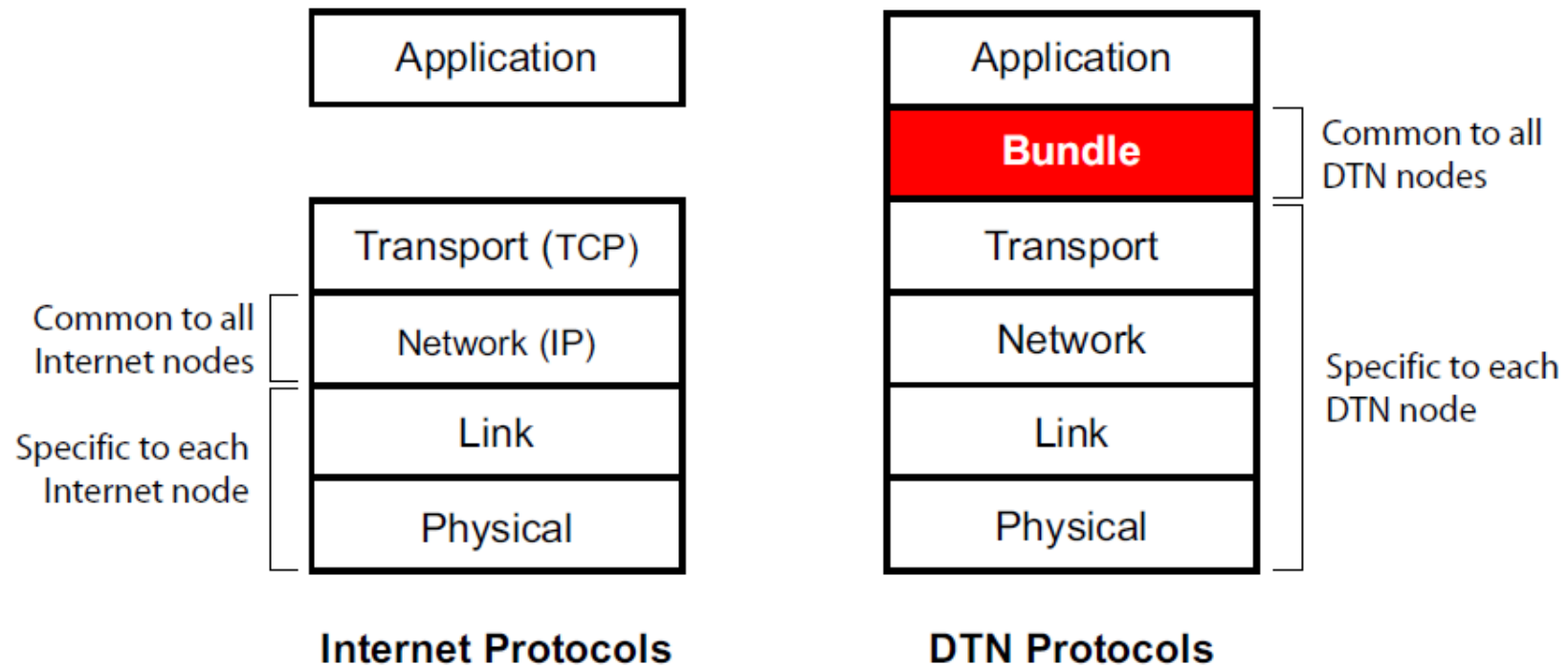
Solution suggestion with a DTN

- Each reindeer carries a collar with a sensor application that collects data about the reindeer's position. The sensor application **stores this data**.
- The collar also includes a network technology that can support intermittent connectivity, for example. LoRa, LTE-M, Bluetooth Low Energy.
- When a reindeer is close to a gateway / base station acting as a sink, the sensor application connects to this sink and **uploads the stored data**.
 - The application could be implemented so that reindeers share data with each other when the are close to each other. In this case, a reindeer uploads all its stored data when it connects with a base station.



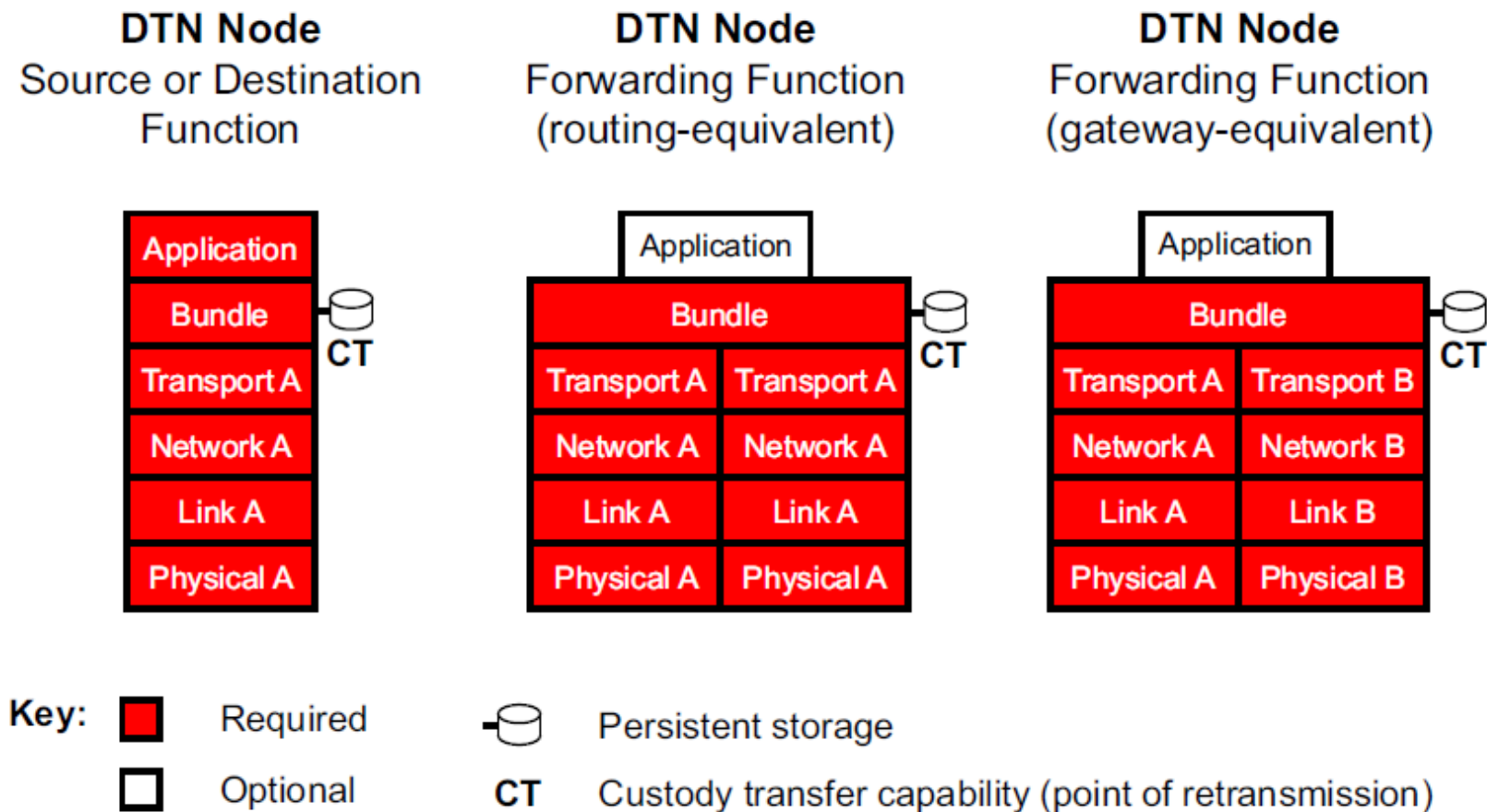
DTN protocol standard: The Bundle protocol

The Bundle protocol is an IETF standard (For use on Earth) and a CCSDS standard (For use in space). The Bundle protocol implements store-and-forward message on top of lower-layer protocols.



DTN nodes

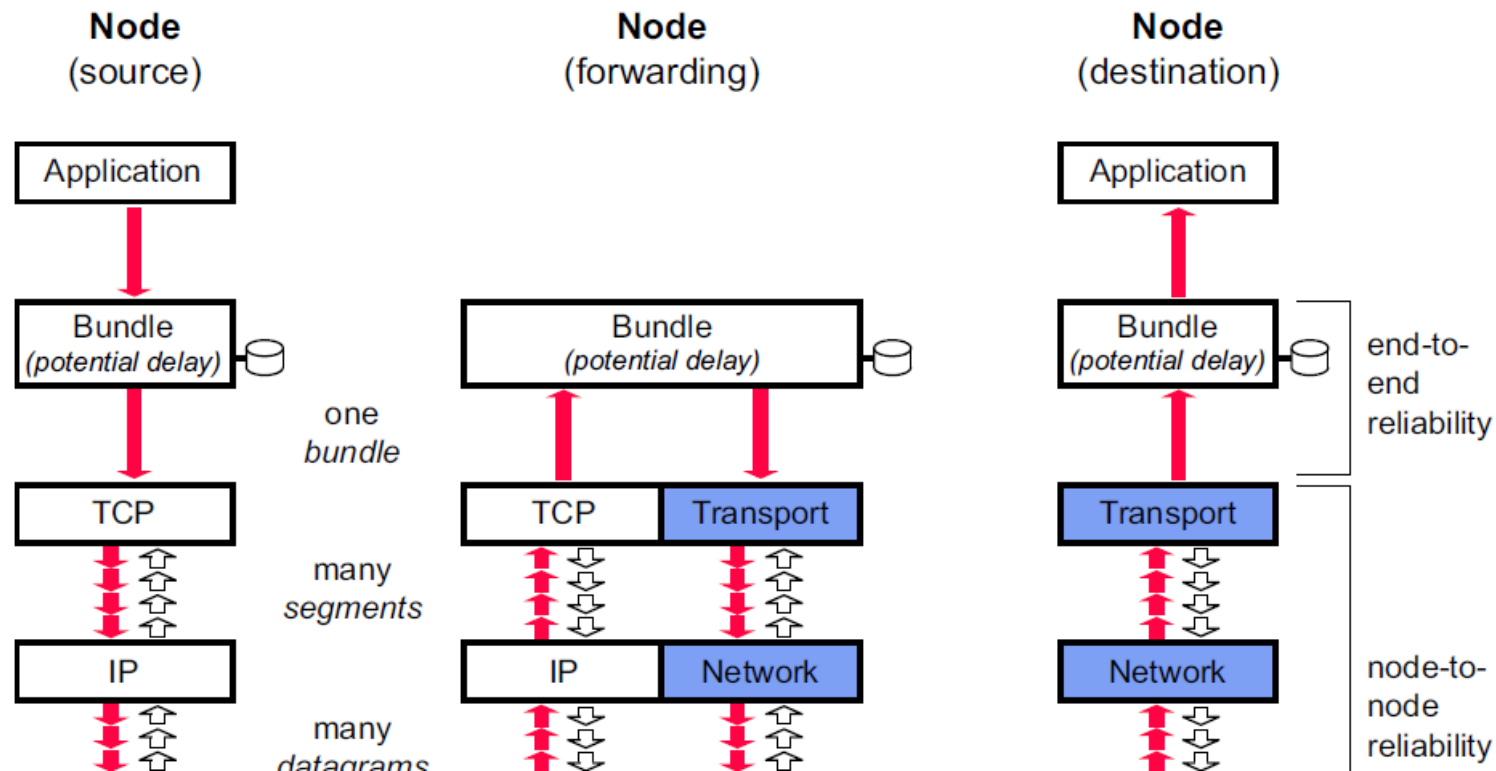
A DTN node (DTN router) is an entity with a bundle-protocol agent overlaid on lower-layer communication protocols.



Delay Isolation via Transport-Protocol Termination

All DTN nodes **terminate lower-layer transport protocols**.

- This means that conversational lower-layer protocols (as TCP) are isolated by the bundle protocol from long delays elsewhere in the end-to-end path.



Custody transfers

- The Bundle protocol supports node-to-node retransmission by means of **custody transfers**.
- When the current bundle custodian sends a bundle to the next custodian, it requests a custody transfer and starts a time-to-acknowledge retransmission timer.
- If the next bundle-protocol agent accepts custody, it returns an acknowledgment to the sender.
 - If no acknowledgment is returned before the sender's time-to-acknowledge expires, the sender retransmits the bundle.
- A bundle custodian must store a bundle until either
 - (1) another node accepts custody, or
 - (2) expiration of the bundle's time-to-live, which is intended to be much longer than a custodian's time-to-acknowledge.

Summary

- Delay- and Disruption Tolerant Networks (DTNs) is a concept that can be used when ordinary conversational protocols do not work.
- A DTN is implemented on the application layer.
- A DTN uses one or more wireless network technologies for communication between nodes.
- In a DTN, data is stored and then forwarded to another node when a link is available.
- Data dissemination in a DTN can be performed in single-hop or multi-hop, depending on the application.



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