Introduction to Delay/Disruption Tolerant Networking

Part I

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Traditional networks vs DTNs

Traditional Networks

- Continuous, bidirectional end-to-end path
- Relatively short round-trip delays
- Low error rates
- Symmetric data rates

Delay Tolerant Networks

- Disruptive connectivity
- High propagation delays
- High bit error rates (BER)
- High bandwidth asymmetry

Delay Tolerant Networking

Based on the

Bundle Protocol

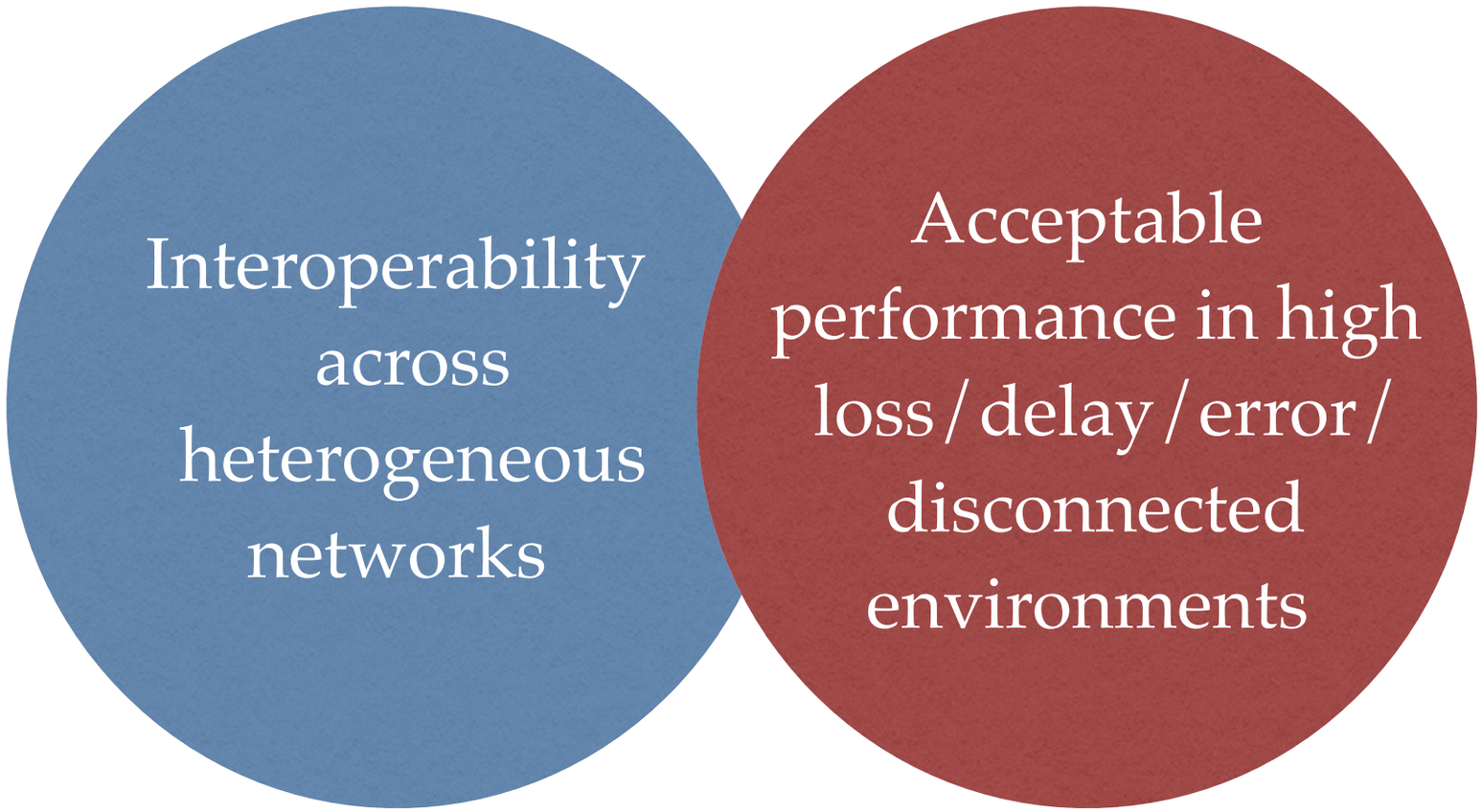
Key feature:

Custody transfer

Enables seamless communication
between diverse devices and technologies
in a *store-and-forward* manner

Complete end-to-end path between source and destination
may not exist in time

Key goals of DTN



Artemios G. Voyiatzis, “A Survey of Delay- and Disruption- Tolerant Networking Applications”, Journal of Internet Engineering, Vol. 5, No 1, Kleidarithmos Press, June 2012

Interplanetary Internet

DTN applicability areas

1. Satellite and deep-space communications

DTN applicability areas

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2. Mobile ad hoc networks (MANETs)

DTN applicability areas

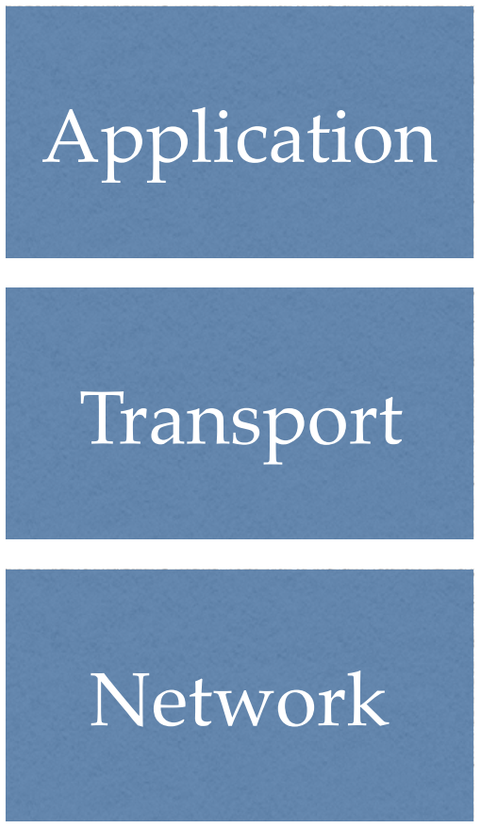
1. Satellite and deep-space communications
2. Mobile ad hoc networks (MANETs)
3. Wireless sensor networks (WSNs)

Bundle layer

- Overlay on top of existing networks between transport and application layers
- Hides the actual network-specific communication layers
- A DTN node can be host, gateway or router
  - *RFC 5050 - Bundle Protocol Specification*
  - *RFC 4838 - Delay Tolerant Networking Architecture*

Data unit: **Bundle**

Typical communications



DTN communications

Application

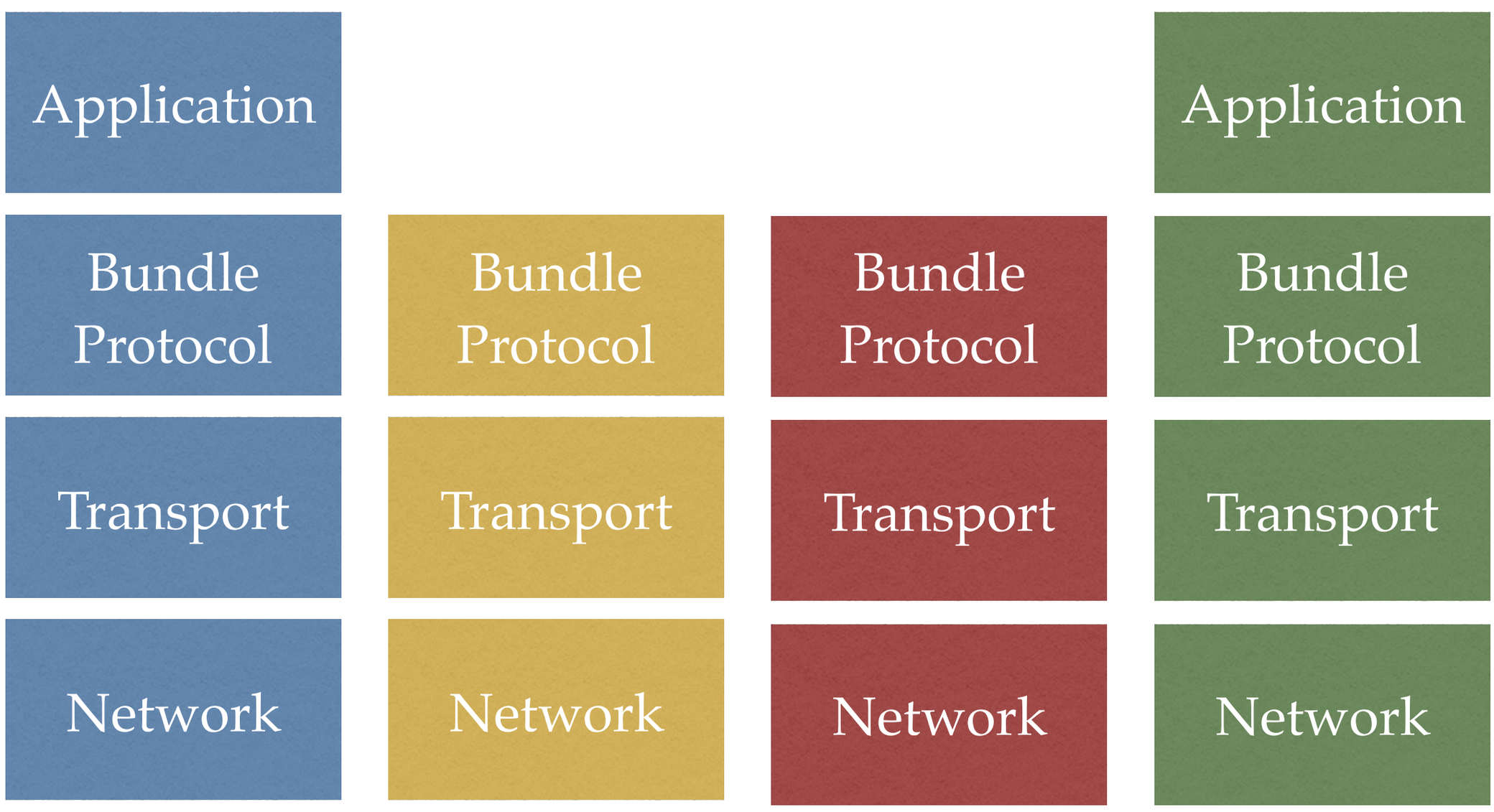
Bundle Protocol

In-transit storage

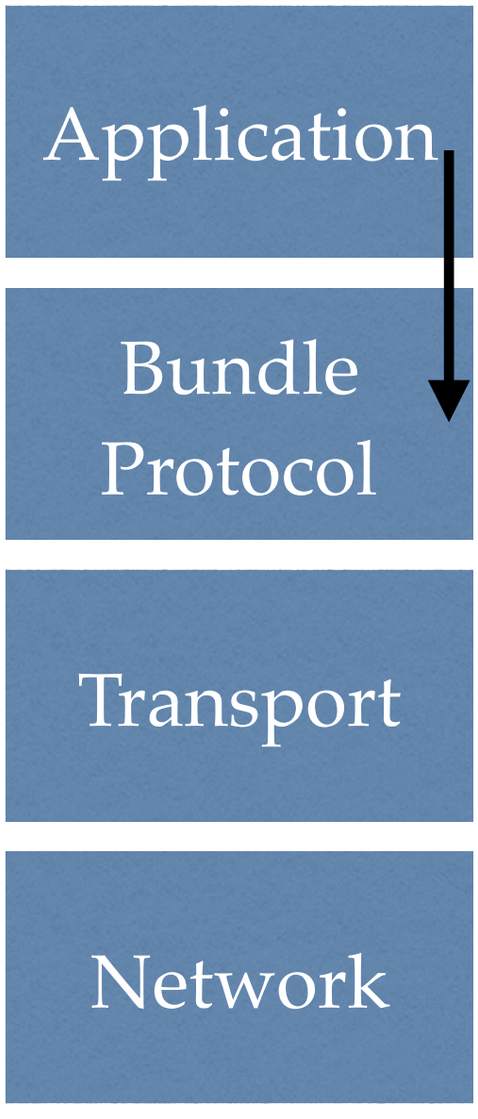
Transport

Network

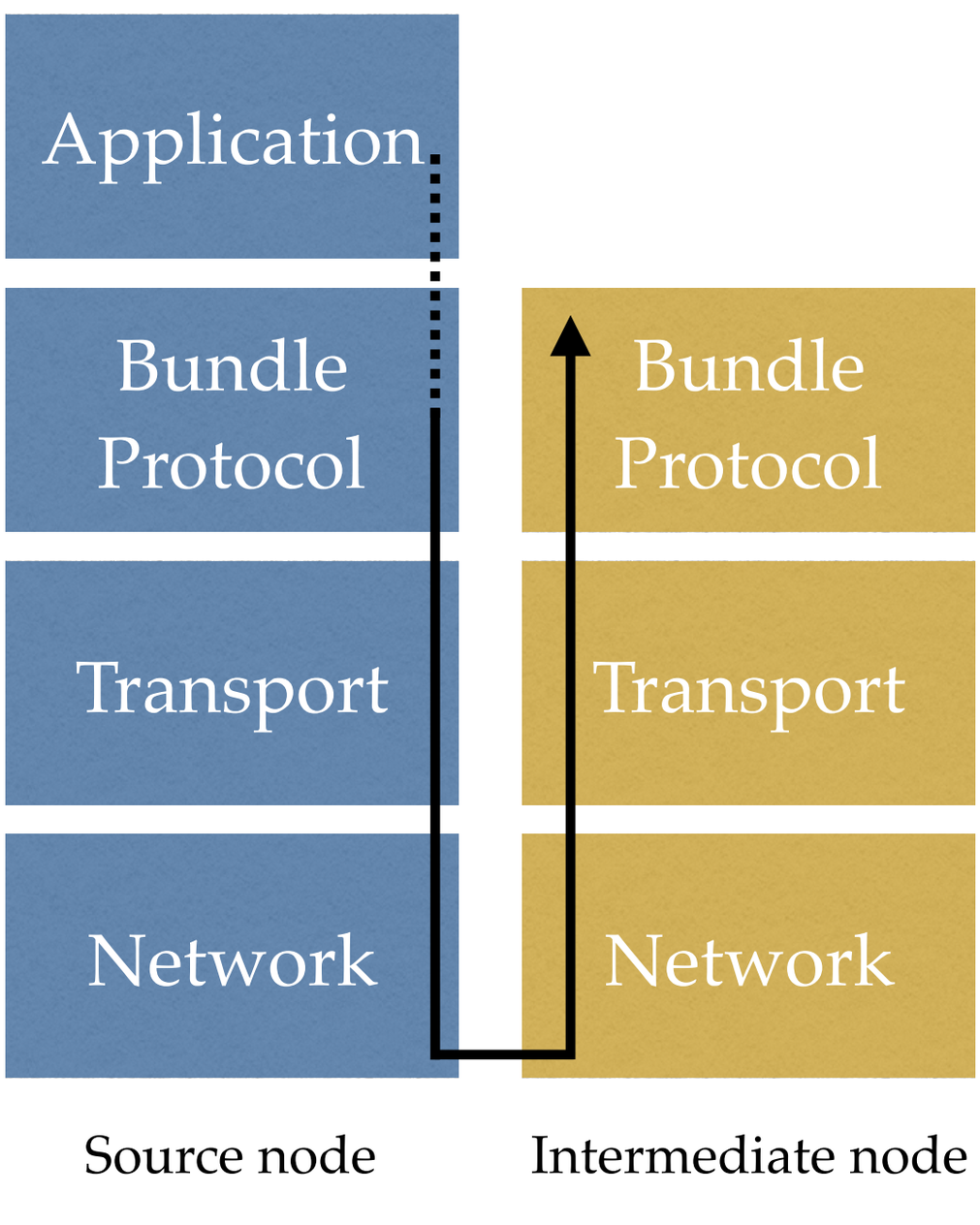
DTN operation



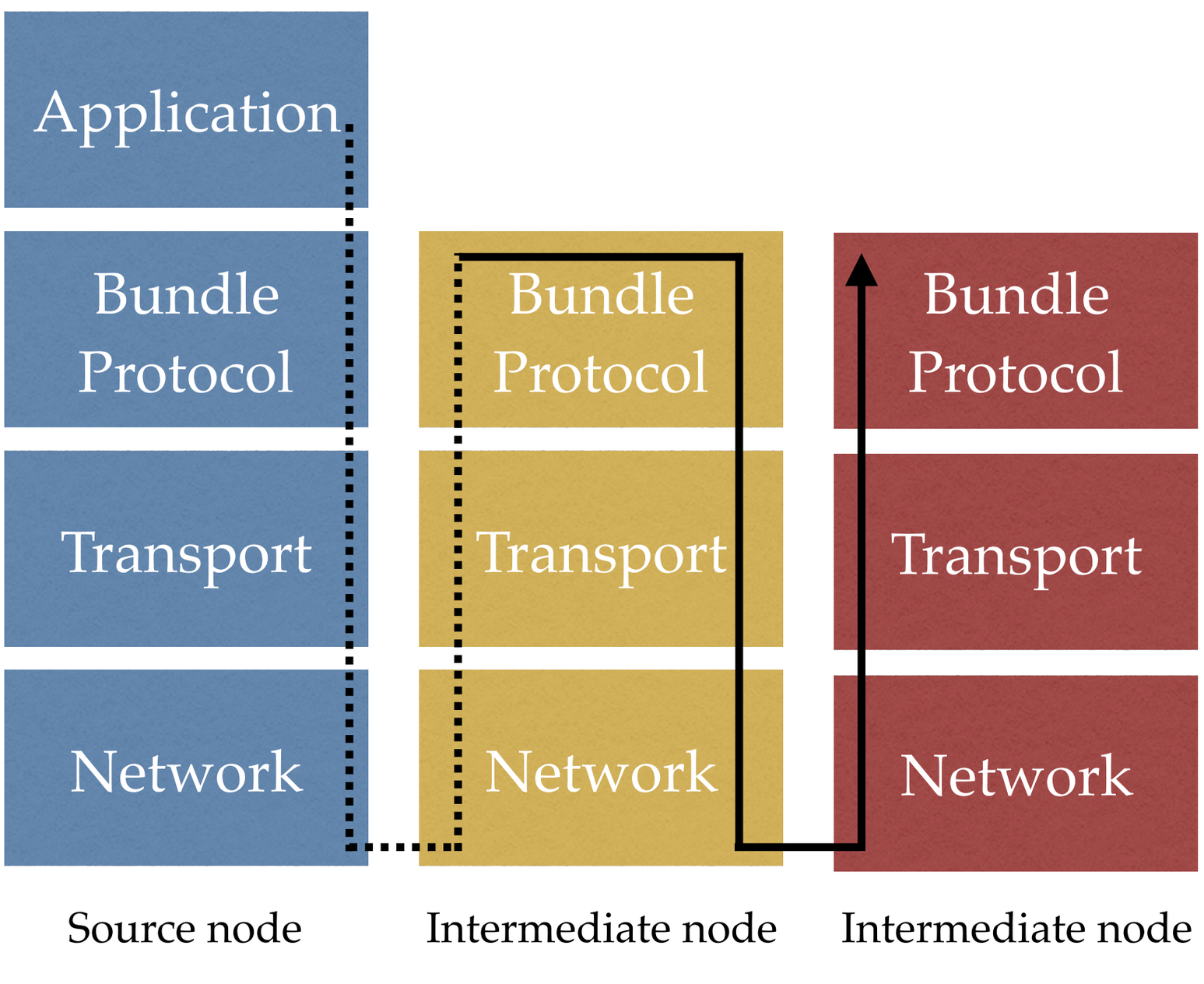
DTN operation



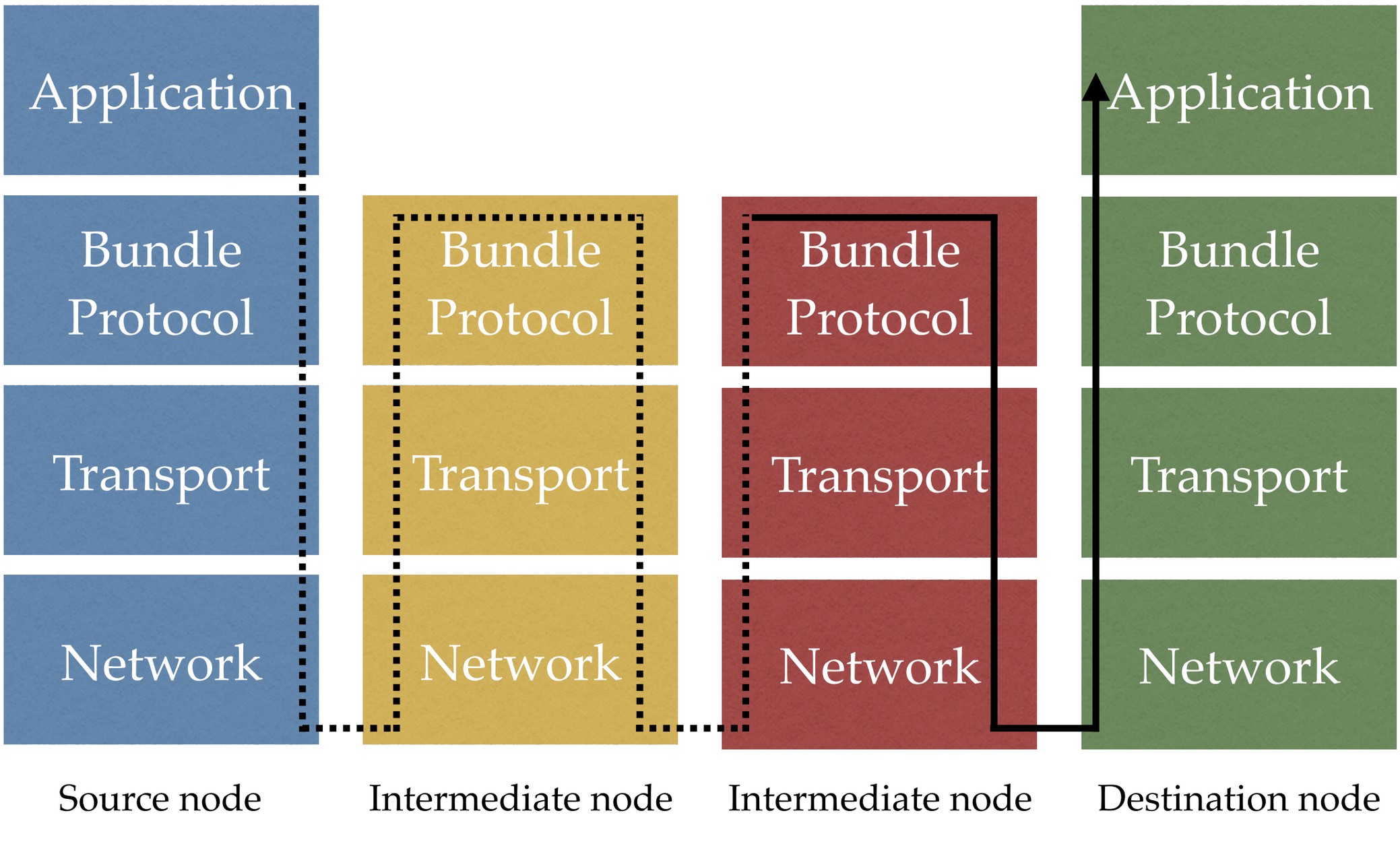
DTN operation



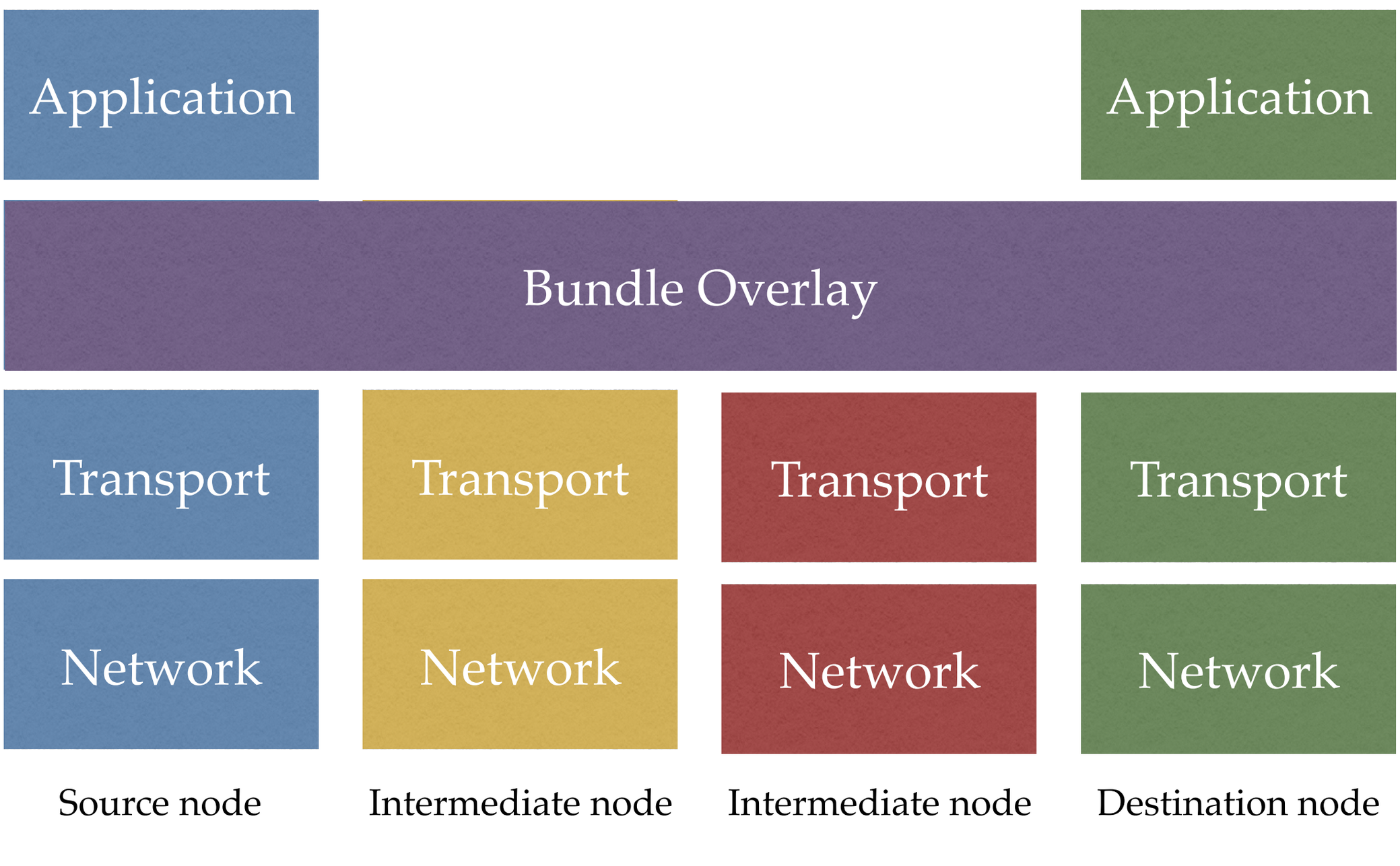
DTN operation



DTN operation



Bundle overlay



Convergence layer

- Abstracts the characteristics of lower layers to the bundle protocol
- In charge of sending and receiving bundles on behalf of the bundle protocol
- Allows for any set of lower protocols to be used to reliably transfer a bundle between two DTN nodes

UDP

TCP

LTP

Primary bundle fields

- Creation Timestamp
- Lifespan
- Class of Service Flags
  - Bulk, Normal or Expedited
- Source EID
- Destination EID
- Report-To EID
- Custodian EID

Custody transfer

- Enhances reliability in DTNs
- Involves moving the responsibility for reliable delivery of bundles among different DTN nodes in the network
- Allows the source to delegate retransmission responsibility and recover its retransmission-related resources relatively soon after sending a bundle

Custody transfer

Source node

Intermediate node 2

Intermediate node 1

Destination node

Custody transfer

Bundle

Source node

Intermediate node 2

Intermediate node 1

Destination node

Custody transfer

Bundle

Source node

Intermediate node 2

Intermediate node 1

Destination node

Custody transfer

Bundle

Source node

Bundle transmitted

Bundle

Custody is accepted
Bundle stored

Intermediate node 1

Intermediate node 2

Destination node

Custody transfer

Source node

Custody
has been accepted
Bundle deleted

Bundle

Custody is accepted
Bundle stored

Custody ACK sent

Intermediate node 1

Intermediate node 2

Destination node

Custody transfer

Source node

Bundle

Intermediate node 2

Bundle

Custody is accepted
Bundle stored

Intermediate node 1

Bundle forwarded

Destination node

Custody transfer

Source node

Intermediate node 2

Custody is denied
Bundle forwarded

Bundle

Bundle

Custody is accepted
Bundle stored

Intermediate node 1

Destination node

Custody transfer

Source node

Bundle

Custody is accepted
Bundle stored

Intermediate node 1

Intermediate node 2

Bundle received

Bundle

Reception ACK sent

Destination node

Custody transfer

Source node

Intermediate node 2

Reception ACK forwarded

Bundle

Destination node

Custody ends
Bundle deleted

Intermediate node 1

Custody transfer

Source node

Intermediate node 2

Bundle

Destination node

Intermediate node 1

Naming

- The destinations of bundles are bundle endpoints, identified by text strings termed "Endpoint IDs" (EIDs)
- A single EID may refer to an endpoint containing more than one DTN node

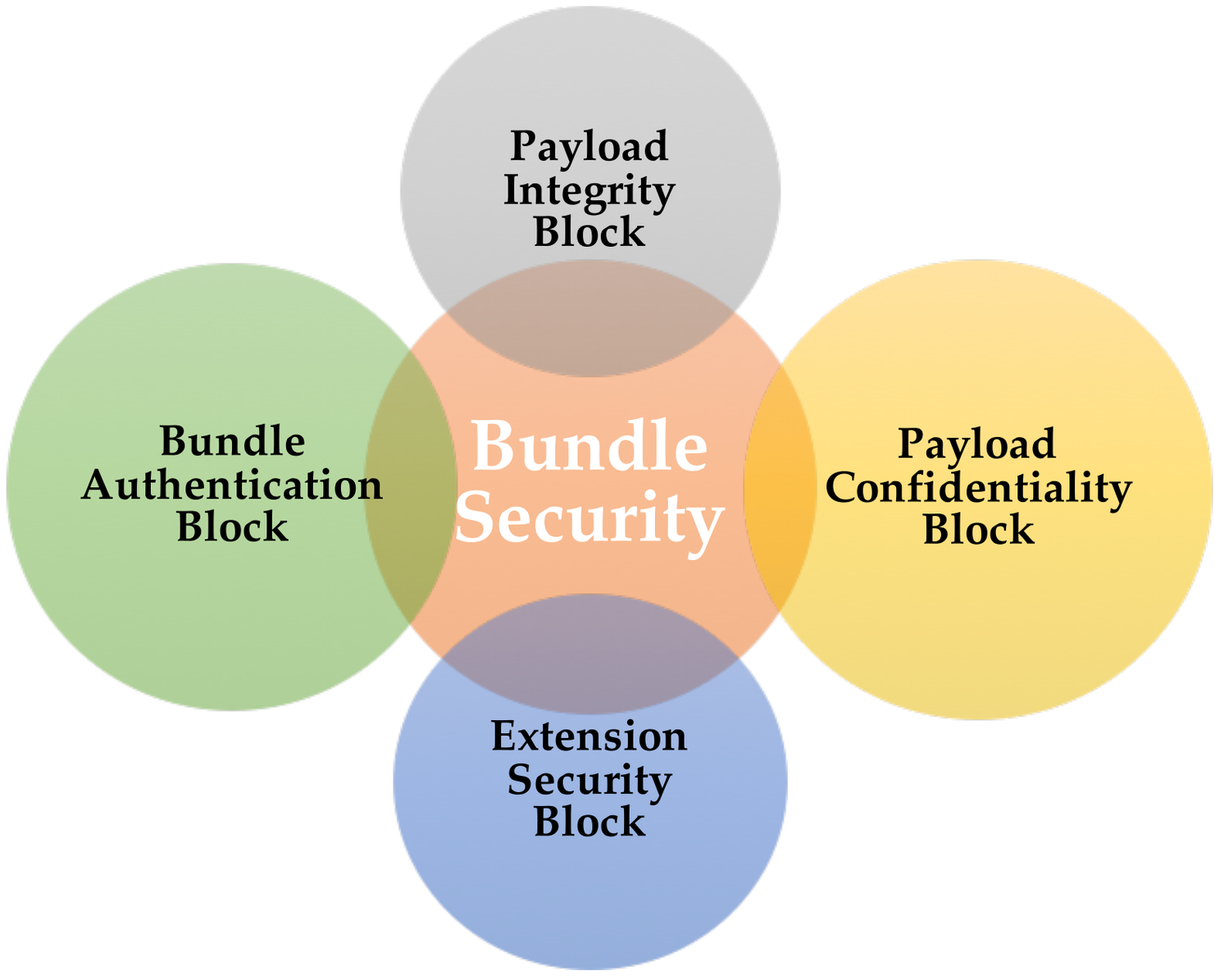
  < scheme name > : < scheme-specific part >

  e.g. dtn://node1

Fragmentation

Proactive	Used when contact volumes are known	The final destination is responsible for collection and reassembly of smaller block
Reactive	DTN nodes may fragment a bundle when only partially transferred	Bundle layer modifies the incoming bundle to indicate that it is a fragment and forwards it

Bundle security



RFC 6257 - Bundle Security Protocol Specification

Standardisation efforts

IRTF DTNRG

- Internet Research Task Force
  Delay Tolerant Networking Research Group

IETF DTNWG

- Internet Engineering Task Force
  Delay Tolerant Networking Work Group

CCSDS

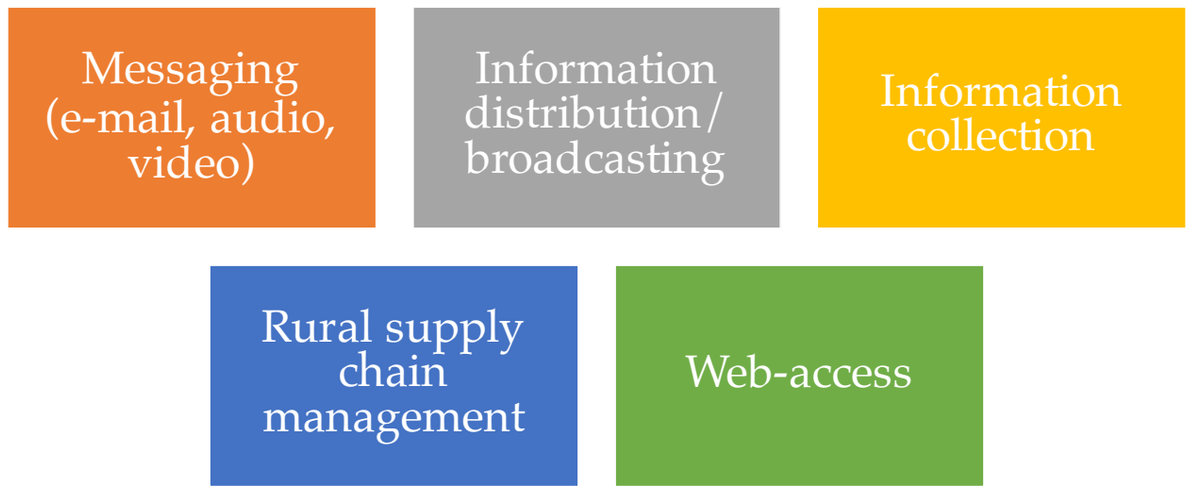
- Consultative Committee for Space Data Systems

DTN use cases

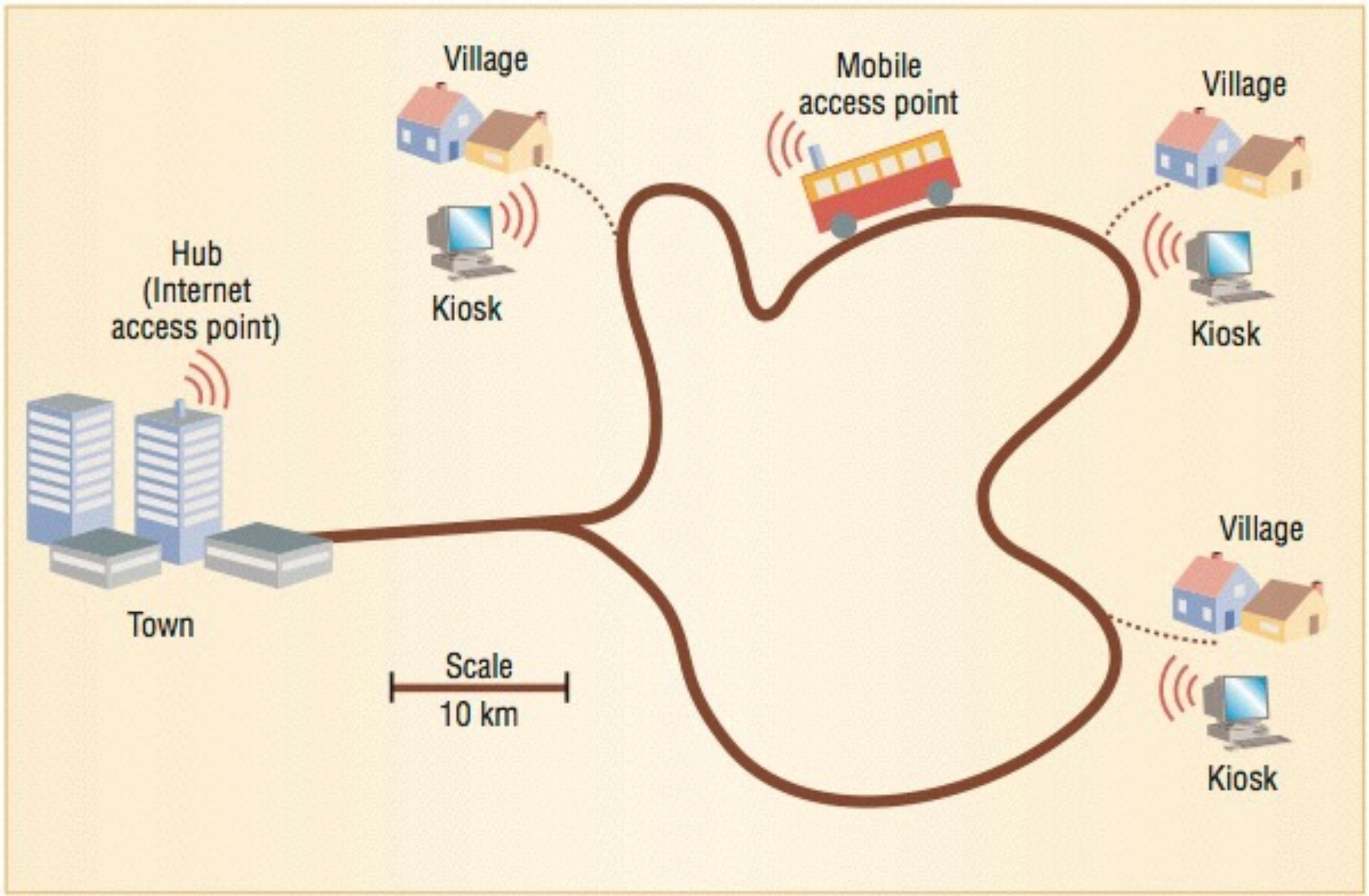
Real-life experiences using delay-tolerant networking

DakNet

- An ad hoc network that uses wireless technology to provide asynchronous digital connectivity
- Developed by MIT Media Lab researchers in 2004
- DakNet has been successfully deployed in remote parts of both India and Cambodia



A. Pentland, R. Fletcher and A. Hasson, "DakNet: rethinking connectivity in developing nations," in *Computer*, vol. 37, no. 1, pp. 78-83, Jan. 2004. doi: 10.1109/MC.2004.1260729


Village
Mobile
access point
Village
Hub
(Internet
access point)
Kiosk
Kiosk
Village
Town
Scale
10 km
Kiosk

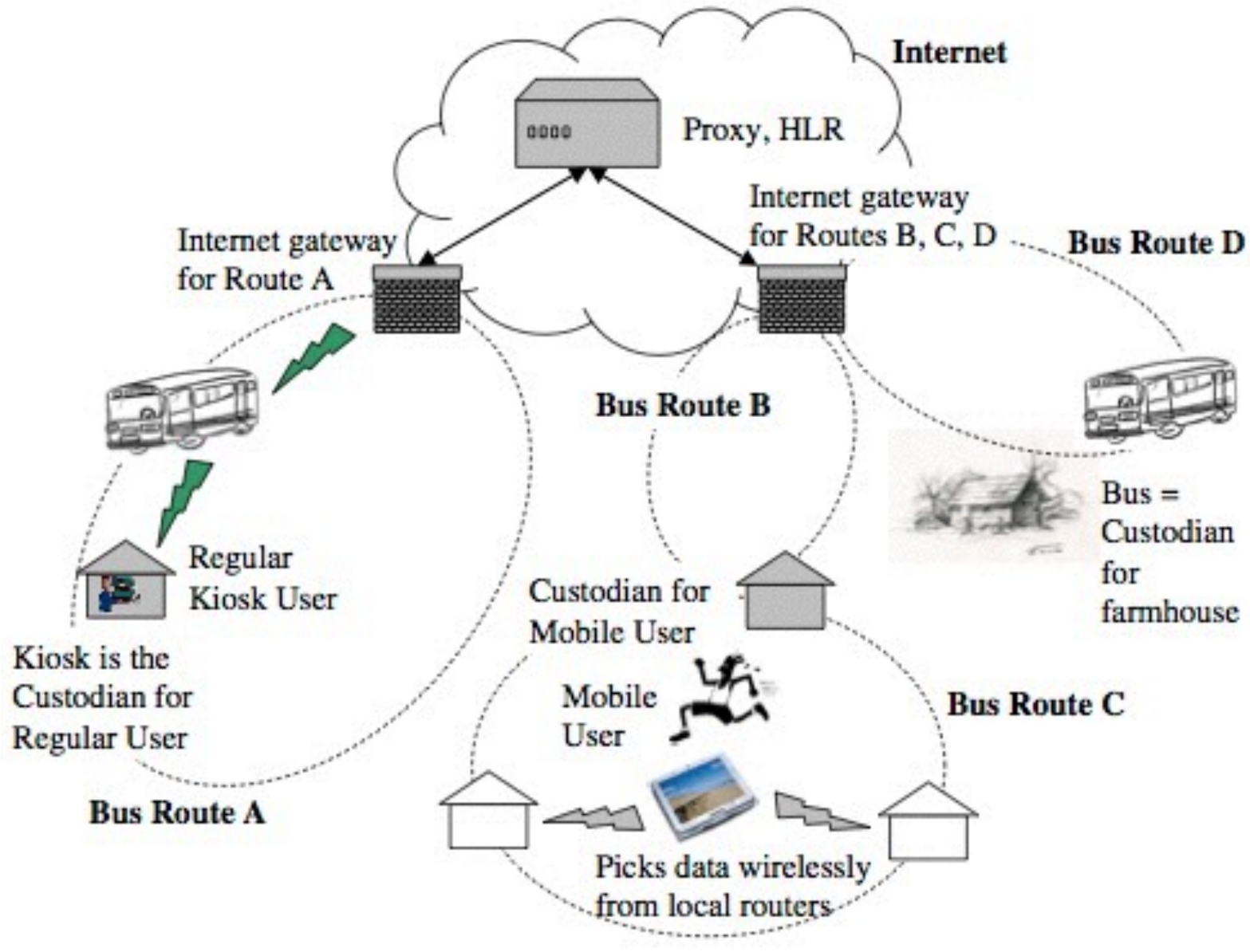
DakNet

KioskNet

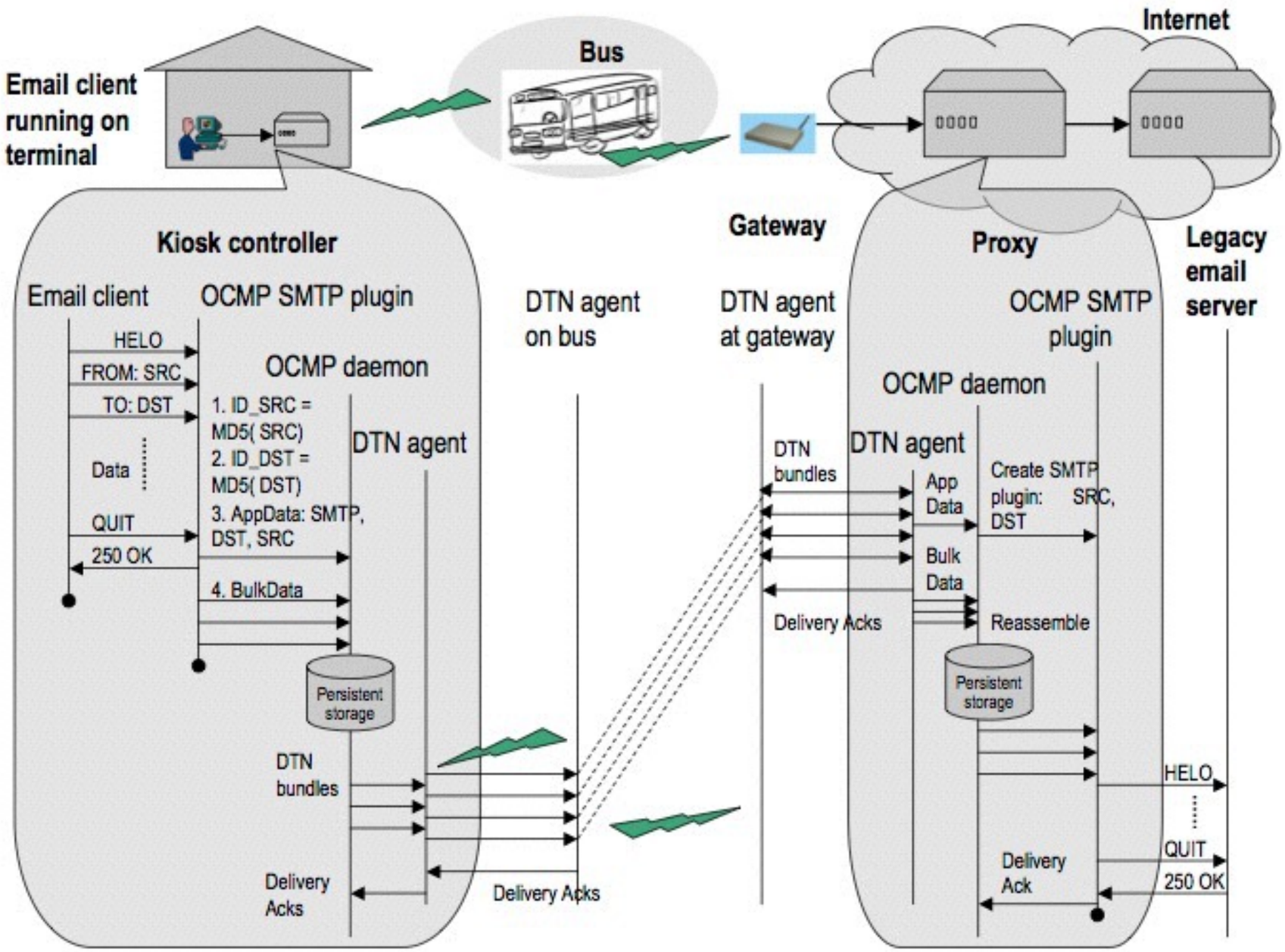
- The kiosk is operated by a computer-literate kiosk owner who maintains the system and assists end-users
- Developed by University of Waterloo in 2006
- Successfully installed a prototype in Anandapuram village, Vishakapatnam district, AP, India

S. Guo, M. H. Falaki, E. A. Oliver, S. Ur Rahman, A. Seth, M. A. Zaharia, and S. Keshav. 2007. Very low-cost internet access using KioskNet. *SIGCOMM Comput. Commun. Rev.* 37, 5 (October 2007), 95-100. DOI=http://dx.doi.org/10.1145/1290168.1290181

KioskNet


Internet
Proxy, HLR
Internet gateway
for Routes B, C, D
Internet gateway
for Route A
Bus Route D
Bus Route B
Bus =
Custodian
for
farmhouse
Regular
Kiosk User
Kiosk is the
Custodian for
Regular User
Custodian for
Mobile User
Mobile
User
Bus Route C
Bus Route A
Picks data wirelessly
from local routers

E-mail using KioskNet



SNC

- The Sàmi Network Connectivity project enables Internet connectivity for the Sàmi population of reindeer herders in the Laponia region in northern Sweden (2006)

- Goal: *To give people new business opportunities and enable things like remote schooling, thus increasing the possibilities of continuing to live in the traditional way and locations*

N4C

- Networking for Communications Challenged Communities (2008-2011)

- Goal: *The development of a lasting testbed for Delay-and Disruption-Tolerant Networking*

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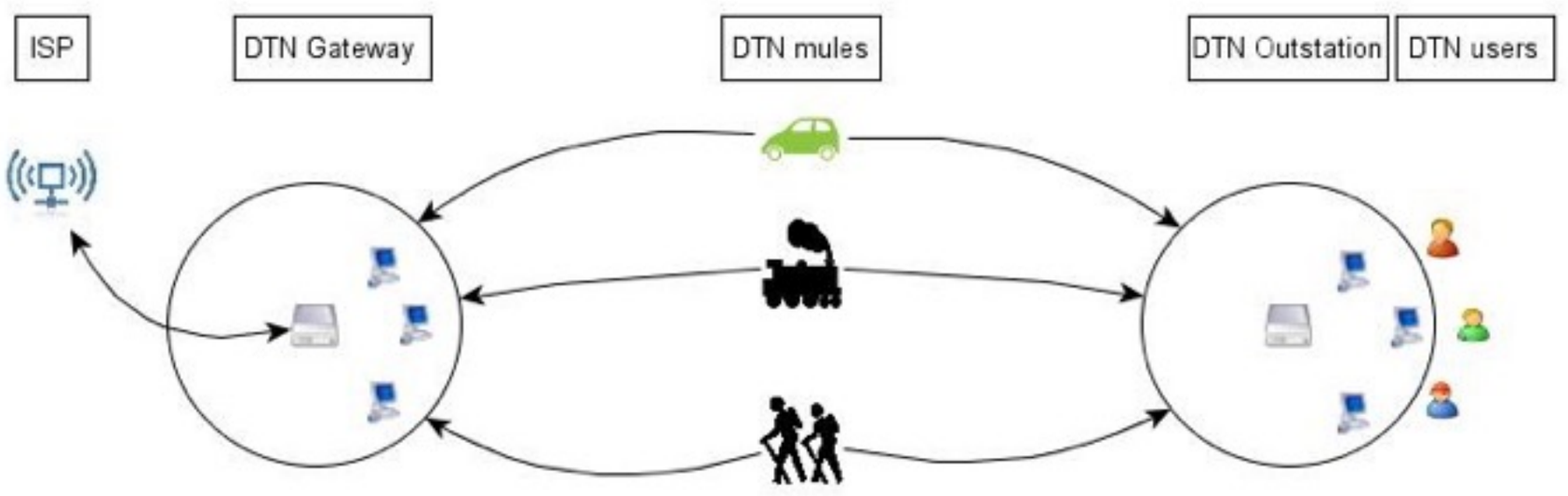


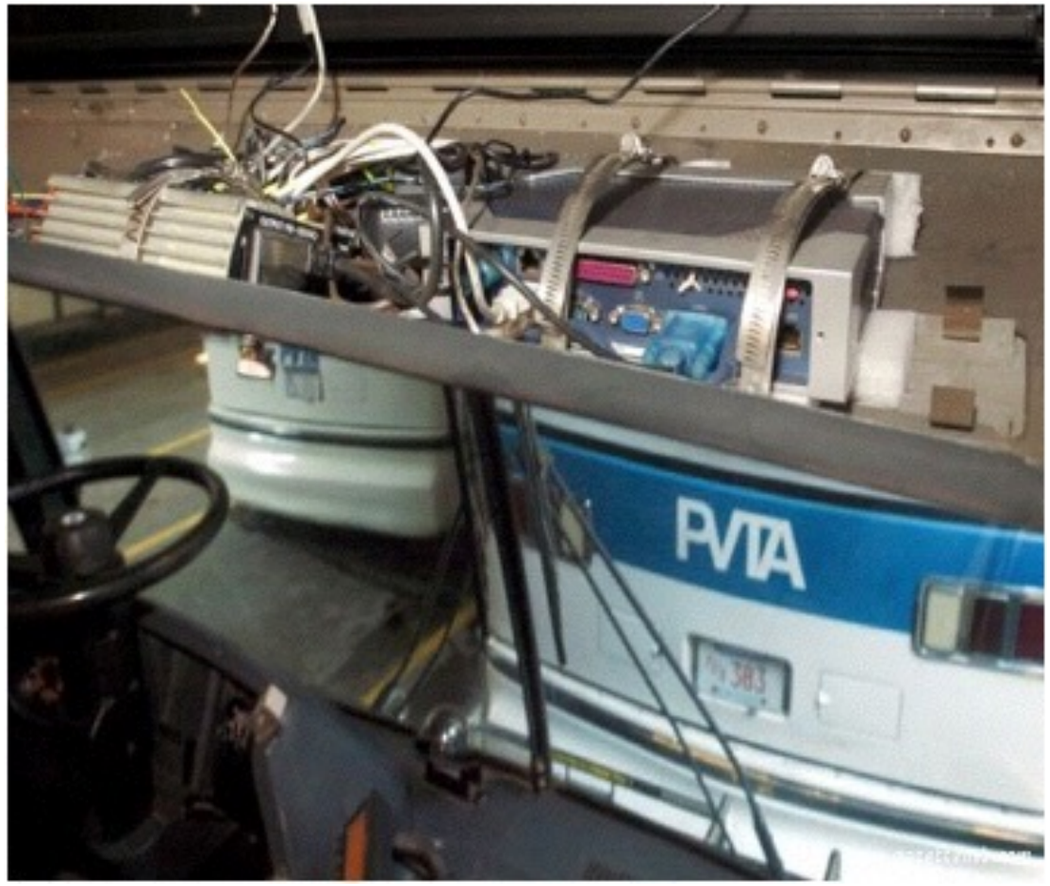
ZebraNet

- Custom tracking collars carried by zebras operate as P2P network to deliver logged data to researchers
- Collars have: GPS, flash memory, wireless transceivers and a small CPU
- Deployed in Mpala Research Center in Kenya in 2004
- Goal: *To understand the long-term migrations of zebras*

Pei Zhang, Christopher M. Sadler, Stephen A. Lyon, and Margaret Martonosi. 2004. Hardware design experiences in ZebraNet. In *Proceedings of the 2nd international conference on Embedded networked sensor systems* (SenSys '04). ACM, New York, NY, USA, 227-238.

DieselNet

- Vehicular DTN deployed in Amherst in 2004-2005
- 40 public transportation buses transfer data as they pass each other and **hotspots**
- Trace available at CRAWDAD.org



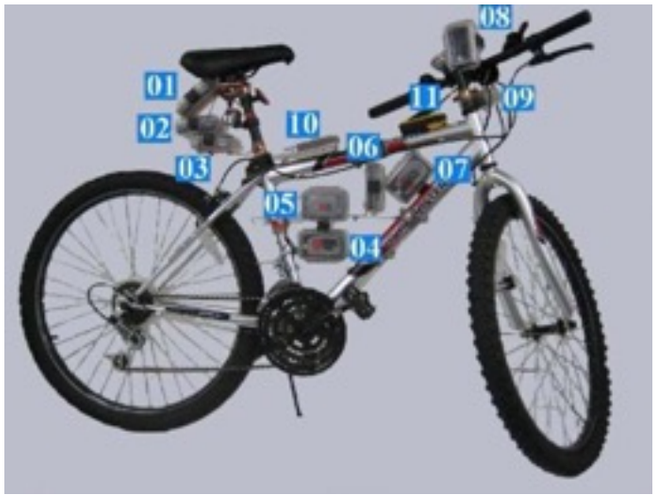
J. Burgess, B. Gallagher, D. Jensen and B. N. Levine, "MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks," *INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings*, Barcelona, Spain, 2006, pp. 1-11. doi: 10.1109/INFOCOM.2006.228

DTN throwboxes

- Stationary, stand-alone wireless nodes powered by a combination of solar panels and batteries
- Act like a transfer points and solve capacity limitations of DTNs
- Using past knowledge, throwboxes can select the most useful contact opportunities in order to meet the energy constraints and maximise the number of packets delivered

BikeNet

- Operates in a *delay tolerant sensing* mode by default, where cyclists go on trips, collect sensed data, and upload their data when they return to home, possibly using the assistance of data mules
- Collected data include:
  - the cyclist's vital info,
  - the cyclist's performance, and
  - the cyclist's surroundings



Shane B. Eisenman, Emiliano Miluzzo, Nicholas D. Lane, Ronald A. Peterson, Gahng-Seop Ahn, and Andrew T. Campbell. 2010. BikeNet: A mobile sensing system for cyclist experience mapping. *ACM Trans. Sen. Netw.* 6, 1, Article 6 (January 2010), 39 pages.

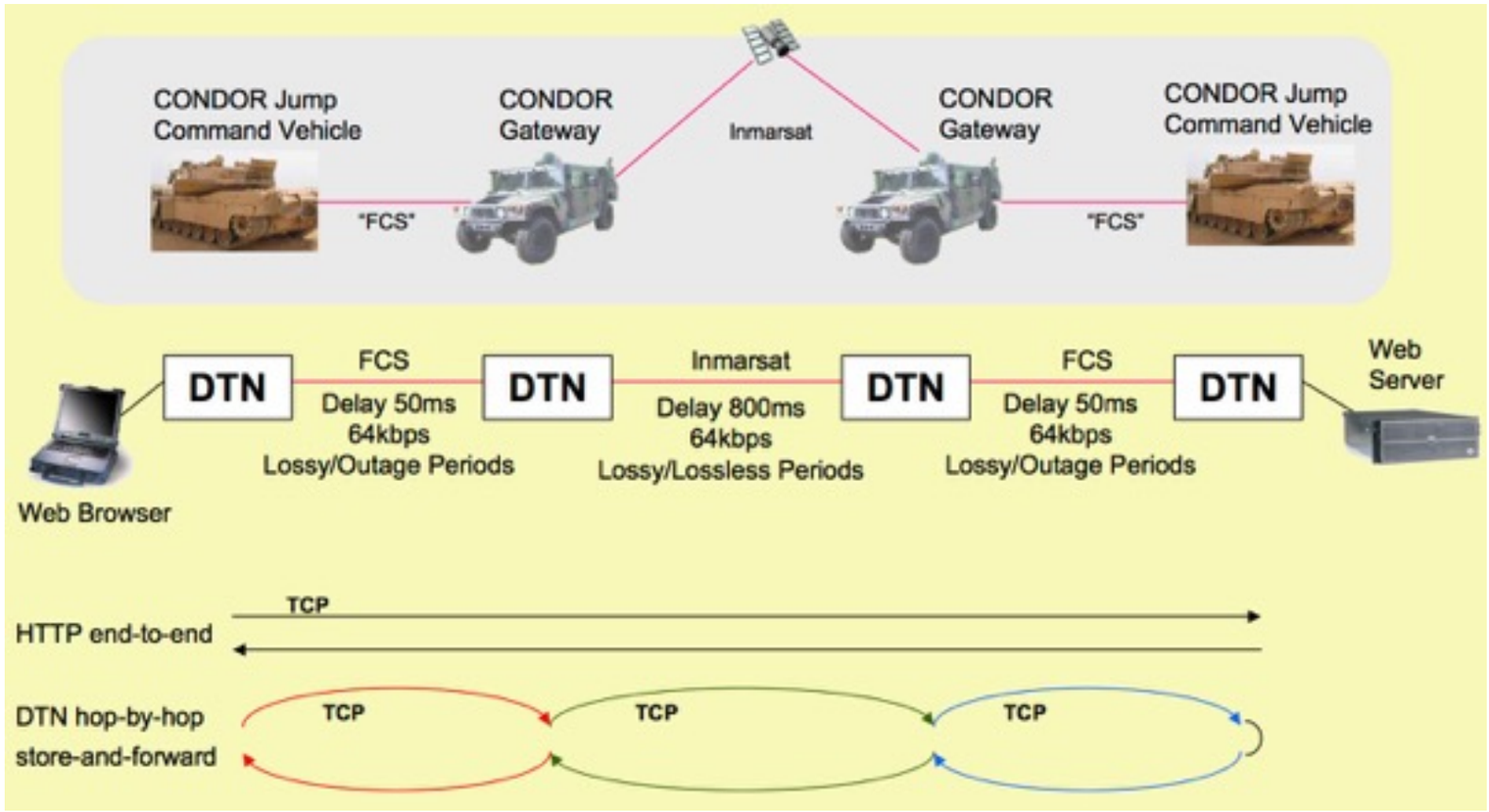
FluPhone

- A mobile phone app developed by Cambridge researchers that tracks how people behave during an epidemic in 2011
- FluPhone provides a software that runs on the users' mobile phones
- There is also a function called 'virtual' epidemics on participants' phones, which gives a real-time picture of the social network between participants from the perspective of infectious disease

https://www.fluphone.org

DTN in military operations

- Future tactical wireless networks will include a diversity of SATCOM, airborne relays, and heterogeneous line-of-sight links



S. Parikh and R. Durst, "Disruption tolerant networking for Marine Corps CONDOR," *Military Communications Conference, 2005. MILCOM 2005. IEEE*, Atlantic City, NJ, 2005, pp. 325-330 Vol. 1. doi: 10.1109/MILCOM.2005.1605705

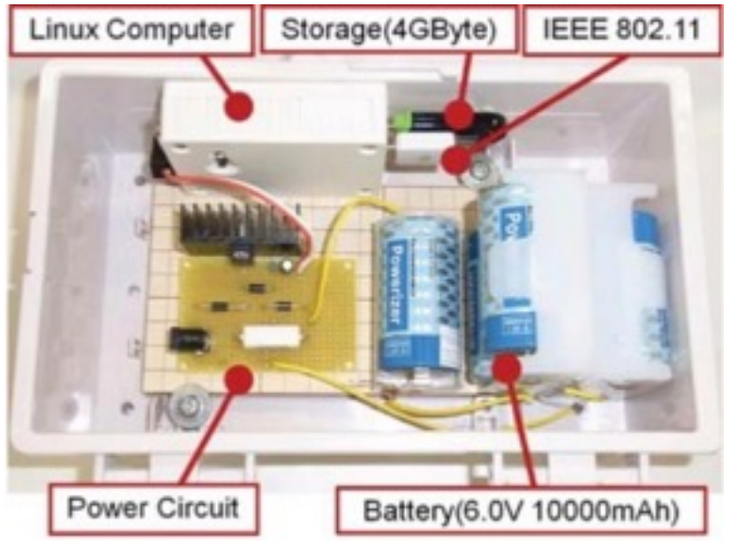
SeNDT

- The Sensor Networking with Delay Tolerance
- Developed in Trinity College Dublin in 2006-2007
- Lake water quality monitoring and urban/ motorway noise monitoring

https://down.dsg.cs.tcd.ie/sendt/

Agricultural sensors

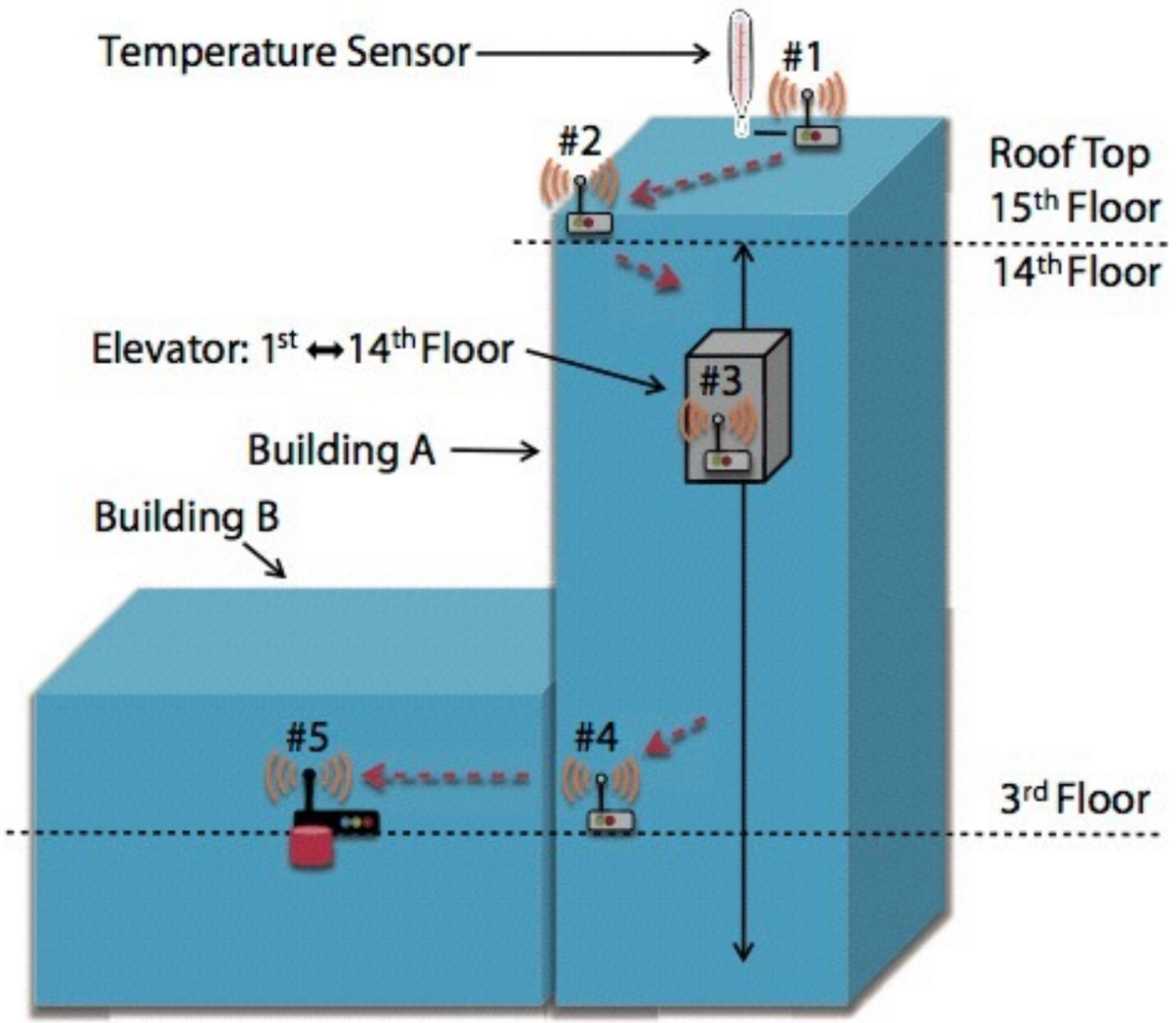
- Sensor data gathering in an agricultural scenario
- Conducted in the University of Tokyo in 2010
- Five weather sensors sparsely in the campus, and vehicular nodes collaboratively collected data from them to our central database.



H. Ochiai, H. Ishizuka, Y. Kawakami and H. Esaki, "A DTN-Based Sensor Data Gathering for Agricultural Applications," in *IEEE Sensors Journal*, vol. 11, no. 11, pp. 2861-2868, Nov. 2011. doi: 10.1109/JSEN.2011.2170562

Urban sensors

- 5 DTN nodes in a building
- Installed at the Technical University of Braunschweig in 2012
- Transfer of temperature measurements from rooftop to a lab using an elevator



W. B. Pöttner, F. Büsching, G. von Zengen and L. Wolf, "Data elevators: Applying the bundle protocol in Delay Tolerant Wireless Sensor Networks," *Mobile Adhoc and Sensor Systems (MASS), 2012 IEEE 9th International Conference on*, Las Vegas, NV, 2012, pp. 218-226.

Underwater sensors

- A DTN testbed with 4 fixed nodes and up to 10 mobile nodes in La Spezia, Italy
- Deployed by NATO's Undersea Research Center (NURC)
- NURC also developed an Underwater Convergence Layer for acoustic communications

D. Merani, A. Berni, J. Potter and R. Martins, "An Underwater Convergence Layer for Disruption Tolerant Networking," *Internet Communications (BCFIC Riga), 2011 Baltic Congress on Future*, Riga, 2011, pp. 103-108. doi: 10.1109/BCFIC-RIGA.2011.5733227

ExtremeCom

- The Extreme Workshop on Communication brings together researchers and practitioners in areas related to DTN and other networking paradigms for rural and remote areas
- Goal: *Gain experience and insight into the challenges that such environments pose for the network and the users*

Laponia, Sweden

Dharamsala, India

Manaus, Brazil

Faulhorf, Switzerland

Eyjafjallajökull Volcano, Iceland

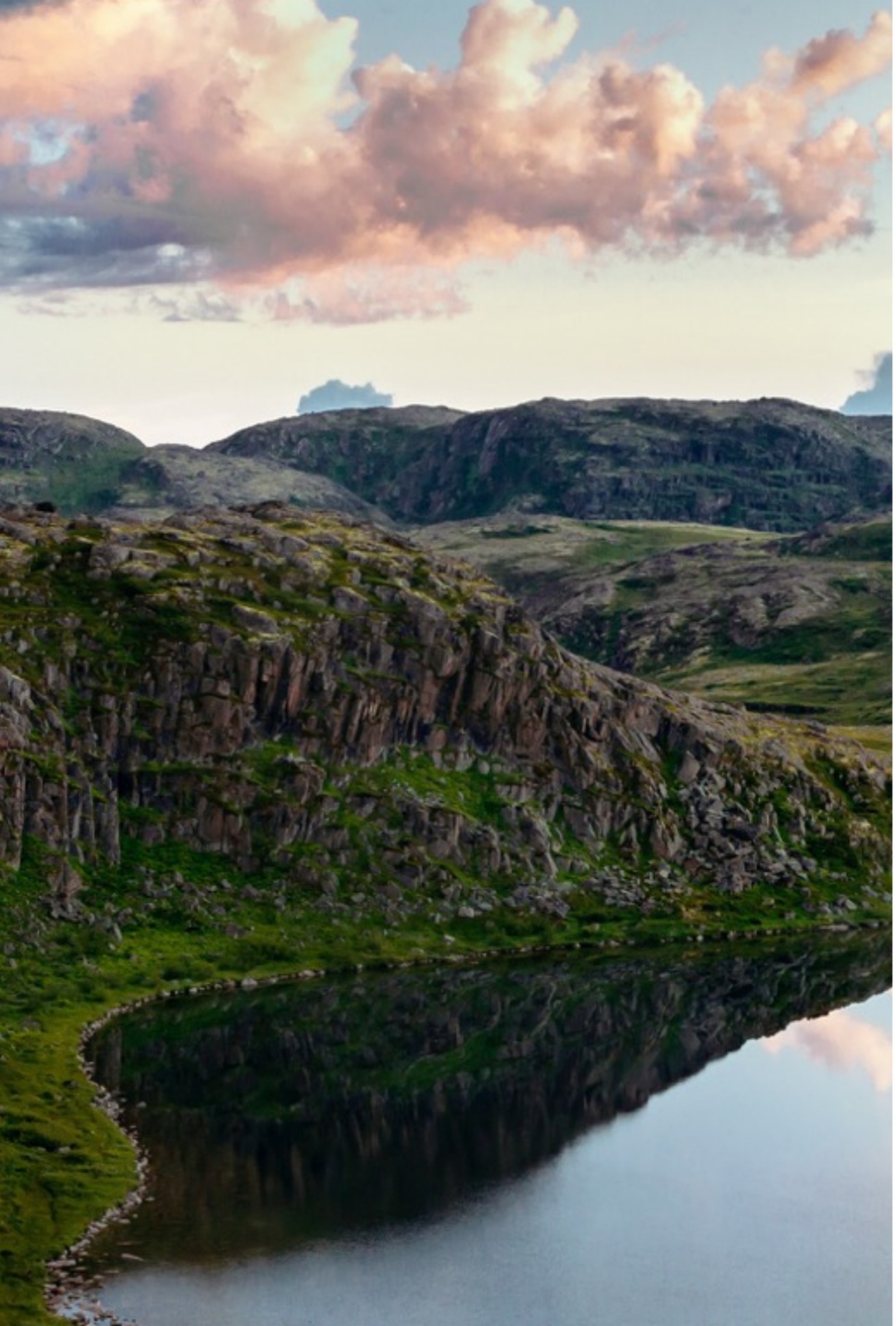
Galápagos islands, Equador

What we learned so far

- What is a DTN?
- How does a DTN operate?
- Show me some real-life DTNs!

Coming up

- DTN in Space
- Which DTN implementations can I download?
- What about simulation tools?
- Existing DTN apps



Thank you for your attention!

Any questions?