A Disruption-Tolerant Internet of Things

Scott Burleigh, the IPN Group

Delay-Tolerant Networking (DTN) as a cost-effective means to extend the reach of the IoT and improve security.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Internet Society™
US San Francisco Bay Area Chapter

Internet of Things

Q: "Internet in space? Who is there to talk to?"

A: Not who – what!

We knew from the beginning that the InterPlanetary Network would be an Internet of Things – orbiters, landers, probes, sensors, robots – for a long time before there'd be many people to send email to.

IoT just means your Things are communicating, with you and with one another.

Internet Society™
US San Francisco Bay Area Chapter

Why isn’t “Internet of Things” simply “The Internet”?

Because Things are different from people:

- **No sense of style, no sense of humor.**
- **No initiative, no curiosity. Things don't get ideas. They don't suddenly need to research topics they're newly interested in.**
- **Infinitely patient, never bored.**
- **Very fast, and they can remember plenty.**
- **They put up with a lot that a person wouldn’t accept, but they’re thrown off by things that a person might make allowance for: oversights, minor errors, small omissions.**
- **And there are going to be many more of them than us.**

Internet Society™
US San Francisco Bay Area Chapter

The Internet is great for conversations

It came to us from telephony.

- **Many of the concepts and legacy terminology were drawn from phone networks.**
- **Telephone carriers were among the first ISPs.**

And that’s how people use it, because people are naturally conversational:

- **We talk with our friends.**
- **We surf the World Wide Web.**
- **We browse online catalogs, magazines, libraries.**

We navigate freely, and we’re annoyed when we click on a link and don’t get a quick response.

Internet Society TM
US San Francisco Bay Area Chapter

But Things don’t care about conversing

Take space probes, for instance:

- **They tell you what they know, as soon as they can. That’s pretty much it.**

Things will ask for information at the moment when they need it, *if* the only way to get that information is to ask for it.

But that “client/server” structure is a legacy architecture, an artifact of the way people use the Internet, which Things have to live with.

Things are more effective – they can respond more quickly – if they *already know* all the information that matters, at the moment when they need it.

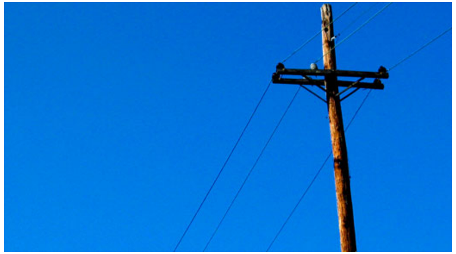
- **Publish/subscribe, asynchronous messaging, “push”.**

Conversation is natural for people but offers no advantage to Things.

Internet Society™
US San Francisco Bay Area Chapter

Which is lucky for us…

…because supporting conversations is expensive.



Internet Society

US San Francisco Bay Area Chapter

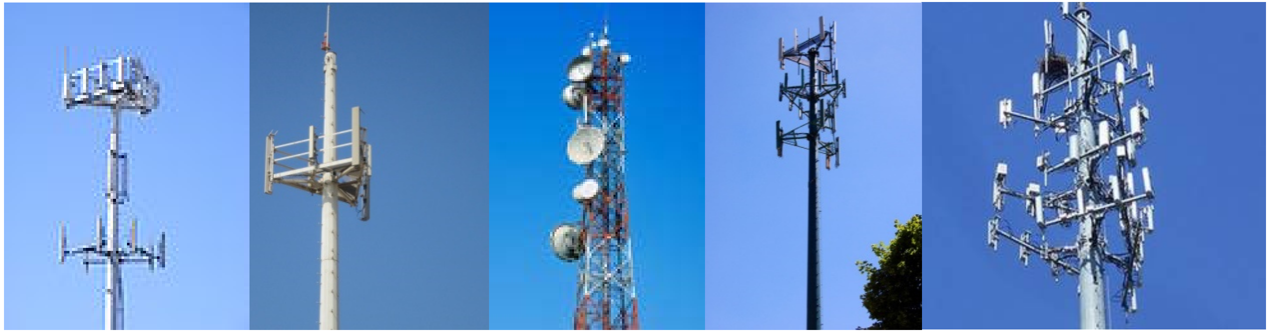
Supporting conversations is expensive…

…because the effectiveness of conversation varies inversely with the incidence of interruptions.

People who have cell phones, for example, are aware of this.

Cell phone service providers compete for customers by trying to provide more reliable, more complete coverage – less "you're breaking up", fewer dropped calls, fewer dead zones.

That means building more cell towers, which costs money.



Internet Society™
US San Francisco Bay Area Chapter

Suppose the Internet of Things is simply more Internet

Data access for Things, as for people, is conversational – client/server.

So network outages degrade data access, which would reduce the effectiveness of the Things.

Many important Things are mobile or are in inaccessible locations, so they can't be wired into the Internet. They have to rely on radio transmission, which is especially susceptible to disruption. This increases their exposure to network outage.

So more infrastructure is needed to improve wireless coverage, to minimize network outages.

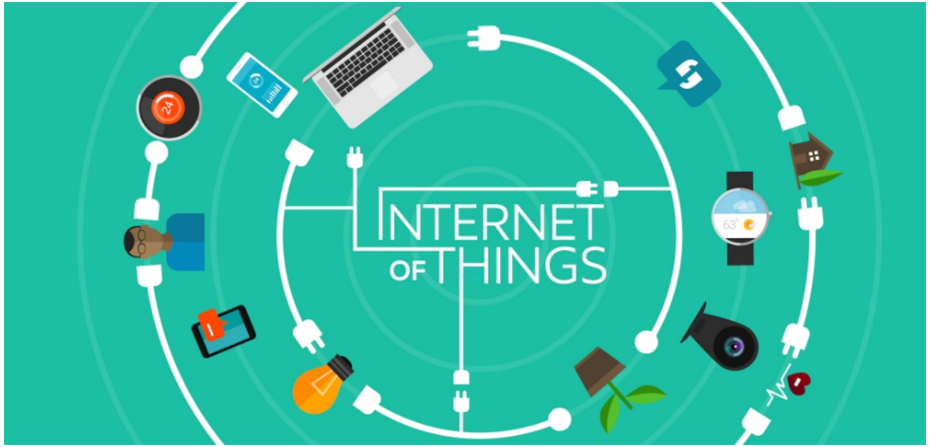
As the number of Things in IoT increases, and as their geographic distribution increases, still more infrastructure is needed.

Internet Society TM
US San Francisco Bay Area Chapter

Moreover…

The growth in the number of Things results in increased traffic. To accommodate the heavier traffic, we migrate to higher radio frequencies, even free-space optical.

But the higher frequencies are even more susceptible to disruption, so growth in the need for more infrastructure accelerates even further.



So the IoT could cost a lot of money.

Internet Society
US San Francisco Bay Area Chapter

And then there's security

Internet protocols guarantee the authenticity and/or confidentiality of data in transit between nodes.

But if a client/server data exchange is interrupted for a few minutes, either the data are lost or else they have to be retained at the sender until the exchange can be retried and completed.

Suppose data loss is not acceptable. The mechanism for retaining the data and later resending the data has to be built into the application.

But the temporarily retained data still need that authenticity and confidentiality, so cryptography has to be built into the application as well, protecting the data at rest.

And there are a lot of applications that will need these functions built in. They are not trivial functions. Sometimes they will be implemented well and perhaps sometimes they won't.

What's the alternative?

When we started looking at interplanetary networking we knew that round-trip times on the network could be long and/or highly variable:

- **The distance from Earth to Mars varies between 3 and 22 light minutes.**
- **If the spacecraft is an orbiter, it's out of view almost half the time.**

So we knew from the beginning that we would need protocols that didn't rely on client/server conversations. The protocols would have to be "delay-tolerant".

But non-reliance on conversations is good for communicating when round-trip times are long or highly variable for other reasons as well: bursty radio interference, passage through tunnels, signal attenuation due to distance from the radio source.

So the same protocols are also "disruption-tolerant". The terms are interchangeable. Luckily they both start with 'D' so we can just say "DTN".

Internet Society TM
US San Francisco Bay Area Chapter

How it works

DTN is an overlay network architecture, interconnecting networks with heterogeneous constraints.

- **The DTN “bundle protocol” (BP) is to IP as IP is to Ethernet.**

- **A TCP connection within an IP-based network may be one “link” of a DTN end-to-end data path; a deep-space R/F transmission may be another.**

Forwarding at a DTN router is automatic but not necessarily immediate: store-[*hold/carry-*]and-forward, with built-in confidentiality and integrity protection for the data at rest.

Reliability depends on retransmission between relay points *within* the network, not only end-to-end retransmission like TCP.

Route computation may have temporal as well as topological elements, e.g., a schedule of planned or predicted contacts.

Internet Society™
US San Francisco Bay Area Chapter

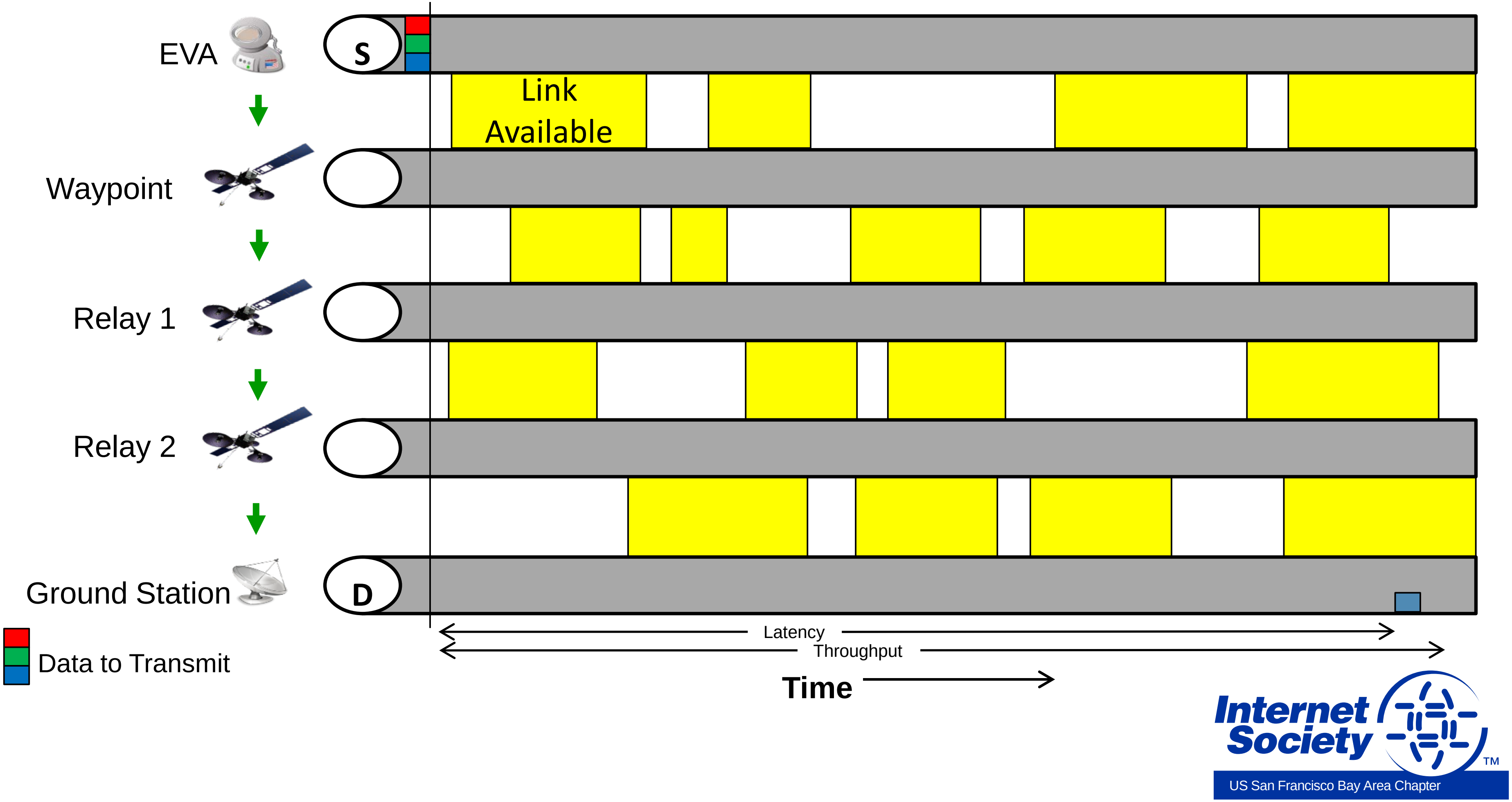
Internet Transfers vs. DTN Transfers

In the Internet: Each received packet is forwarded immediately if possible, deleted if immediate forwarding is not possible. Next-hop destination is computed based on known current network topology.

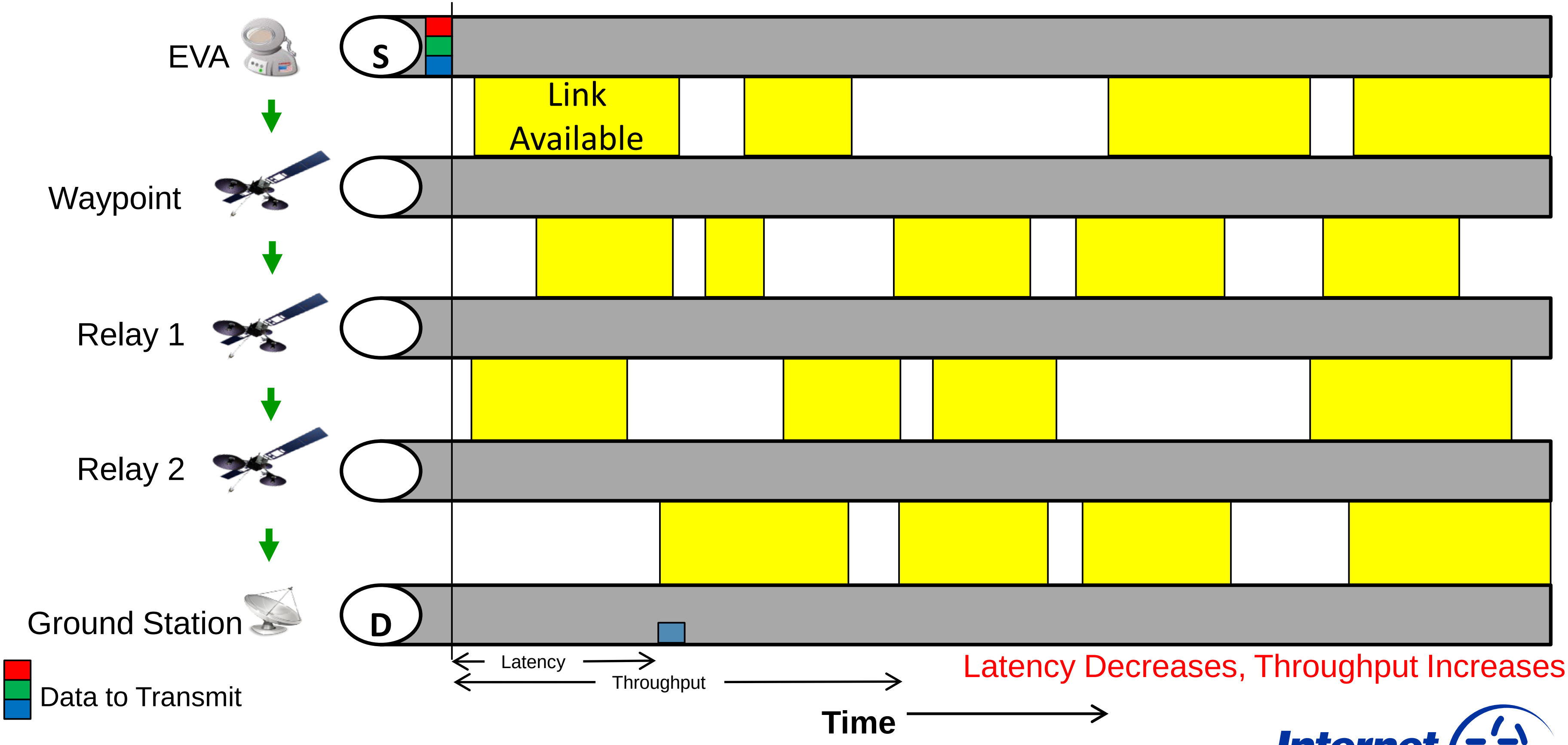
In DTN: Each received packet is forwarded immediately if possible, stored for future transmission if forwarding is not currently possible but is expected to be possible in the future. Next-hop destination is computed based on expectations of future network topology.

Thanks to Adam Schlesinger of NASA Johnson Space Center for this slide and the next two.

Sample Waypoint Scenario Using IP: Complete end-to-end path must be available



Sample Waypoint Scenario Using DTN: Only next hop needs to be available



Internet Society™
US San Francisco Bay Area Chapter

Current Status of DTN

Multiple satellite demonstrations, in low Earth orbit and in deep space. Now being made operational on the International Space Station.

Multiple demonstrations and deployments in terrestrial networks, several sponsored by the European N4C (Networking for Communication Challenged Communities) program.

Multiple open-source implementations available.

Multiple experimental RFCs published since 2007. Now a standards-track DTN Working Group is established in IETF, with initial standards-track RFCs on schedule for publication in 2016.

For more information on DTN, see www.ipnsig.org.

Summing up

DTN is a good fit for the Internet of Things:

- **It can provide the network service that Things need at lower cost than the Internet architecture can.**
- **The standards are open, the software is open-source and proven.**
- **DTN is affordable as it scales up, which IoT is going to do.**

Questions?

Internet Society™
US San Francisco Bay Area Chapter

Thank You

Scott.C.Burleigh@jpl.nasa.gov

Internet Society TM
US San Francisco Bay Area Chapter