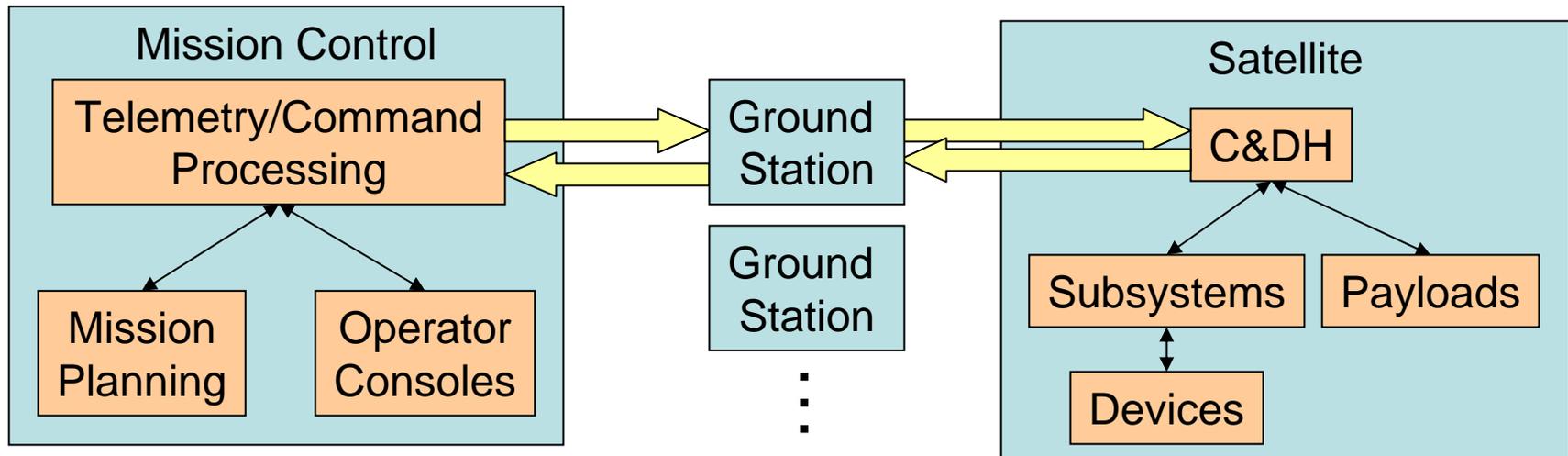


Implications of Internet Protocol on LEO Micro-Satellite Communication Links

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The logo for SpaceDev features the word "SpaceDev" in a blue, sans-serif font. A yellow and orange swoosh underline is positioned behind the text, starting from the left and curving around the right side of the word.

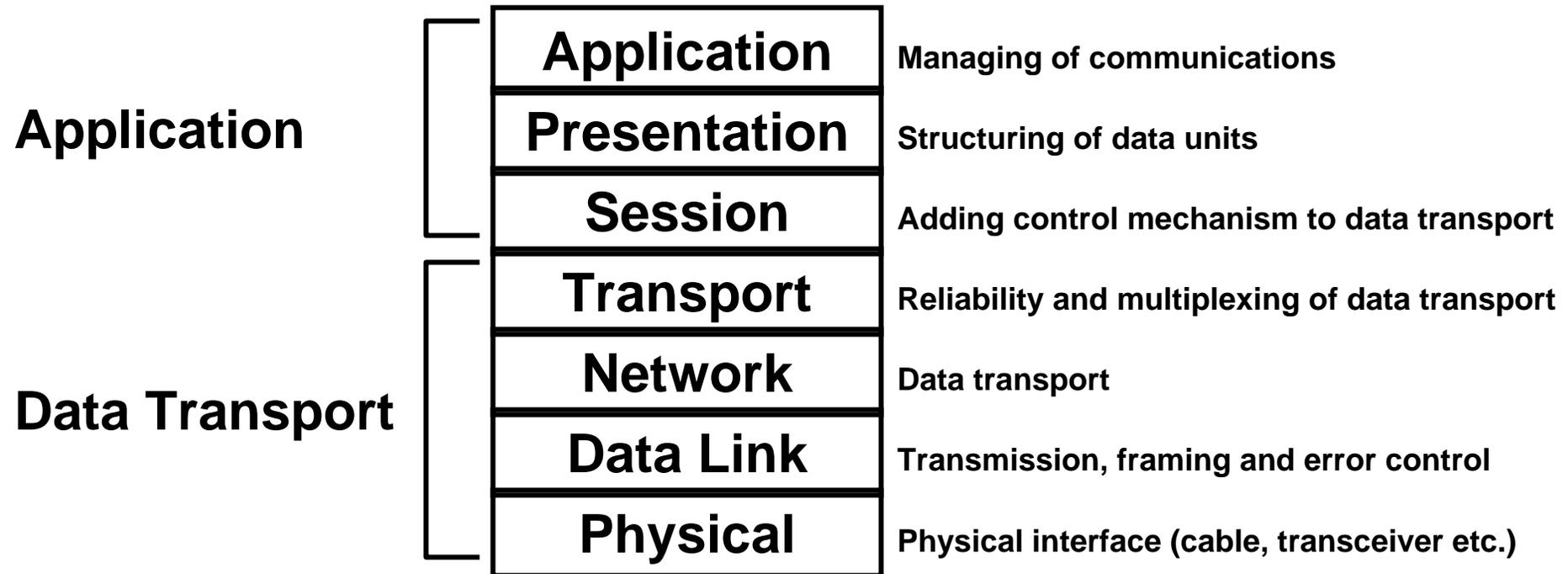
SpaceDev



- Telemetry
 - Format data from devices/payloads
 - Transmit to mission control processing via ground station(s)
 - Extract data and distribute
- Commanding
 - Format command from operator directives
 - Transmit to spacecraft via ground station(s)
 - Extract and validate command before execution

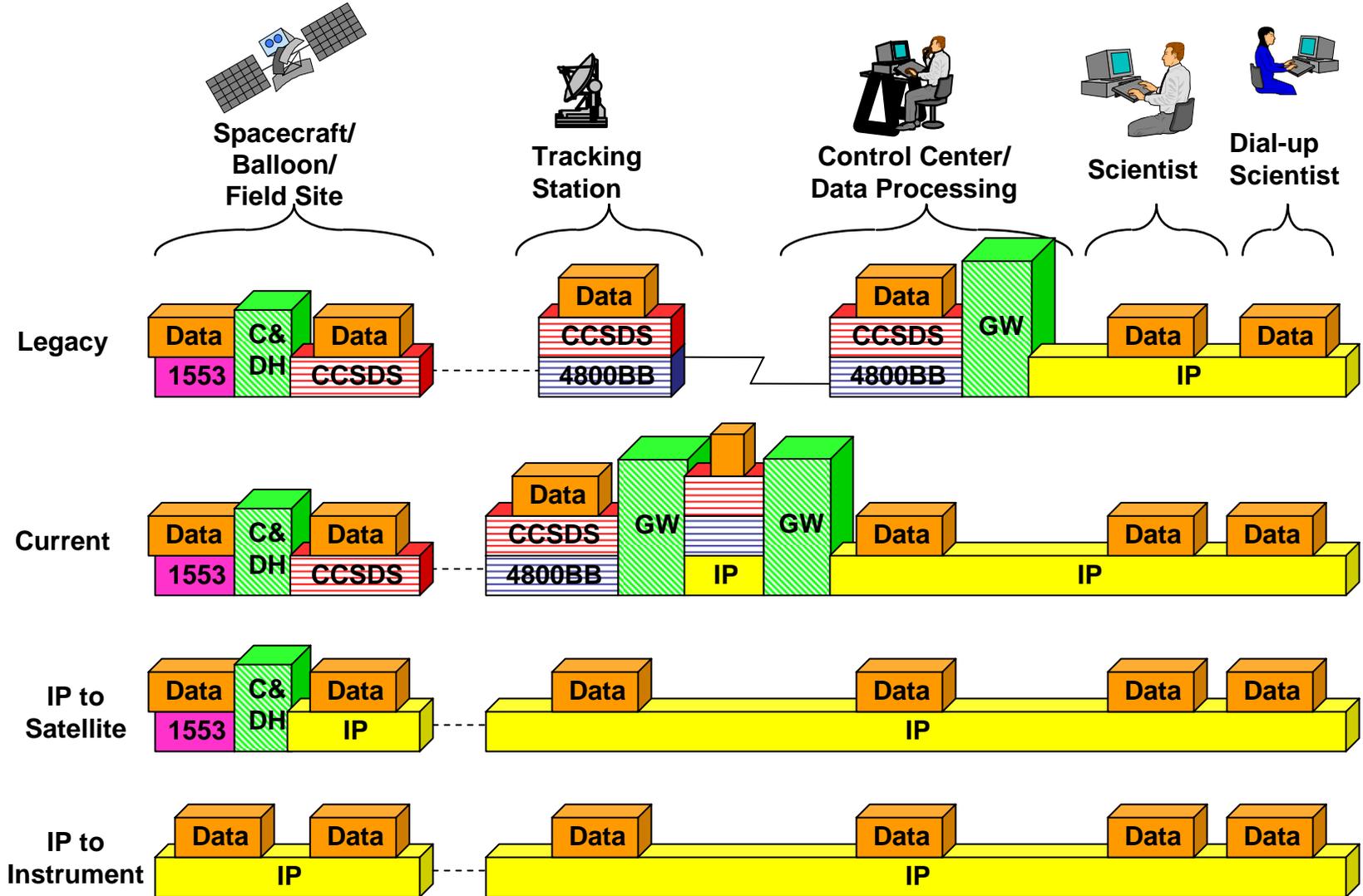
- Time Division Multiplex (TDM)
 - Pulse Amplitude Modulation (PAM)
 - Analog commutator (rotary switch) at one end
 - Synchronized decommutator at the other end
 - Sensitive to noise
 - Frames cannot easily be reconfigured
 - Not in wide use today
 - Much of current spacecraft data link operations are still designed as though PAM was being used
 - Pulse Code Modulation (PCM)
 - Digital
 - IRIG Standard 106-96 standardizes PCM frames
 - Insensitive to noise
 - Frame content requires a high level of coordination
 - Still in wide use today

- Circuit-switched
 - Dedicated data path for some time period
 - Example: AFSCN
 - Packetized protocols can be used
 - But PCM (IRIG) is more common
 - Don't get much benefit from routable protocols (IP)
 - Tight coupling between systems along a circuit leads to higher costs
- Packetized
 - Data is sent in “chunks”
 - Multiple sources can be interleaved
 - Packets can be independently routed
 - Packet protocol is independent of data content
 - Allows layering
 - Two implementations
 - Consultative Committee for Space Data Systems (CCSDS)
 - Cumbersome with mixed layers
 - Great effort to optimize performance for space applications
 - Expensive equipment
 - Internet Protocol (IP)
 - Streamlined with clear layers
 - Great effort to reduce cost for all applications
 - Inexpensive equipment



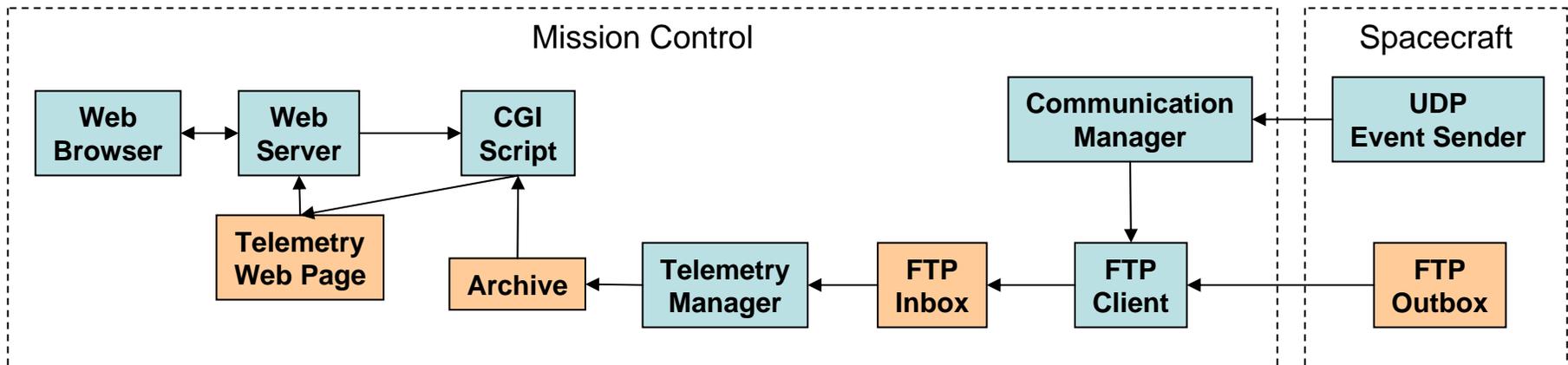
- Each layer has clear interfaces to nearest layers
 - And *only* the nearest layers!
- Modular architecture allows implementing and optimizing each layer independently
 - Reduces development costs
 - Increases availability of COTS technology

End-to-End Space Link Evolution



- User Datagram Protocol (UDP)
 - Best-effort no-acknowledge delivery (one way)
- Transmission Control Protocol (TCP)
 - Reliable acknowledge-based with automatic retransmissions
- Telnet
 - Provides remote login sessions for spacecraft maintenance
- Internet Control Message Protocol (ICMP)
 - Provides network diagnostic tools
- File Transfer Protocol (FTP)
 - Provides multi-session file transfer
- Network Time Protocol (NTP)
 - Synchronize the spacecraft system clock with the ground
- Simple Mail Transfer Protocol (SMTP)
 - Deliver status messages
 - Built-in support for store-and-forward
- Hyper-Text Transfer Protocol (HTTP)
 - Provide operator interfaces for command and telemetry
- Internet security
 - Plethora of technology is available
 - Many companies rely on secure Internet communications
 - Internet does not necessarily mean poor security!
 - Proper use of available IP measures gives wide range of security levels
 - Choose the level (and cost) that you need

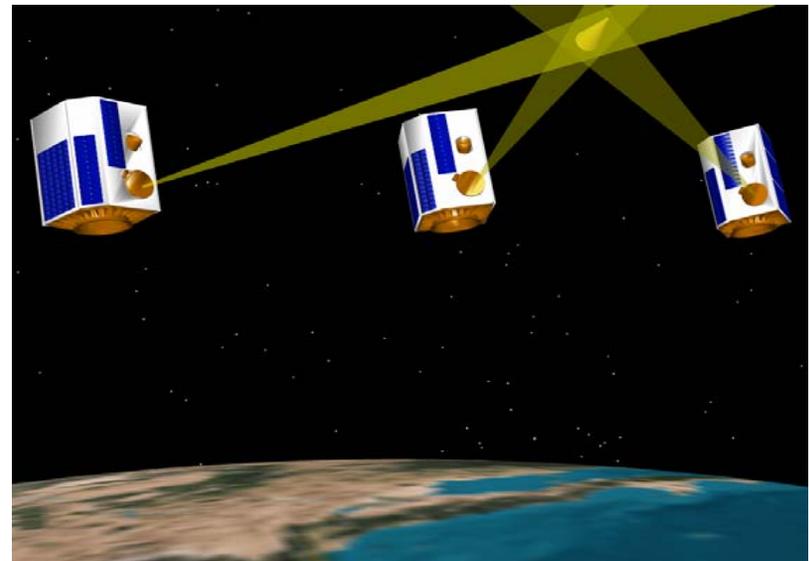
- Spacecraft turns on S-Band transmitter at the scheduled time
 - Begins sending UDP health and status (brief) telemetry
- Ground station starts tracking satellite at scheduled time
 - Mission Control server (PC) starts getting UDP events
 - When comms are established, comm manager notifies all registered observers
- FTP client grabs all files in the spacecraft outbox and notifies all register observers
- Telemetry manager gets notified that new log files are available
 - Moves files out of Mission Control server inbox
 - Copies files to archive
- Web browser executes periodic refresh
 - Executes CGI script on web server to grab latest telemetry and format it into web page
- Analysis console can get telemetry log files from archive
 - Convert to CSV file format
 - Run analysis tools such as MATLAB, STK, or Excel





- Launched January 12, 2003 and still flying
 - Over three years of operation – designed for only one year
- First spacecraft to use IP/HDLC as primary means for command and telemetry
 - 115.2 kbps downlink
 - UDP, NTP, FTP, ICMP
- Average about 2-3 contacts per day with 16 MB/day
 - Over 20 GB of data transferred over IP space link to date
- After three years, UC Berkeley continues to be pleased with the IP based systems

- Pushing IP to sensor
 - Spacecraft bus becomes a wireless router for payloads
- Using IP/HDLC for next microsatellite mission
 - Three identical microsats flying in formation
 - Each more capable than CHIPSat
 - 1800 DMIPS COTS flight computer with 256 MB RAM and 8 GB flash
 - Running GNU Linux OS
 - 512 kbps downlink
 - HW encrypted link
 - Because of layering, software is not impacted at all
 - TCP (reliable) normal mode commands
 - UDP (best effort) summary telemetry and emergency commands
 - FTP compressed telemetry log files
 - Telnet for spacecraft software maintenance



- Internet Protocol on the space link applies a mature, hugely successful network layering model
 - Layering reduces software complexity
 - Reduces development costs and risks
 - Enables using cost-reducing COTS IP technology
 - Low-cost COTS hardware and software
 - COTS IP diagnostic tools
 - Simplifies testing (just plug into your LAN!)
- Why isn't IP being used more on spacecraft?
 - Many confuse IP with TCP (one of many protocols on top of IP)
 - TCP does not perform well in an increased error and high latency environment
 - Lots of discussions on a space-specific replacement for TCP
 - Thanks to layering, this would be *completely transparent* to the application software!
 - In LEO, generic TCP is good enough (according to our experience and that of others)
 - But probably is not a good solution past GEO
 - IP, however, has no intrinsic latency limit
 - Many perceive the message overhead (2-6%) for IP is unacceptable
 - If you must squeeze every bit out of your link, IP isn't for you
 - Most modern satellites have margins larger than 6% (CHIPSat has a 26% margin)
 - There are existing IP header compression schemes for constrained terrestrial links
 - Corporate inertia
 - "We've never done it that way before"
 - Existing infrastructure and experience bias towards old approaches
 - Reluctance to embrace anything that does not have a long space track record
- For microsat applications we've studied, the benefits of IP far outweigh the limitations

Non-IP

- Specialized design
 - Higher data efficiency
- Higher HW/SW cost
- Well-understood by aerospace people

IP

- Generic design
 - More flexible
- Lower HW/SW cost
- Well understood by everyone else!

