



Communications Infrastructure for Fractionated Spacecraft

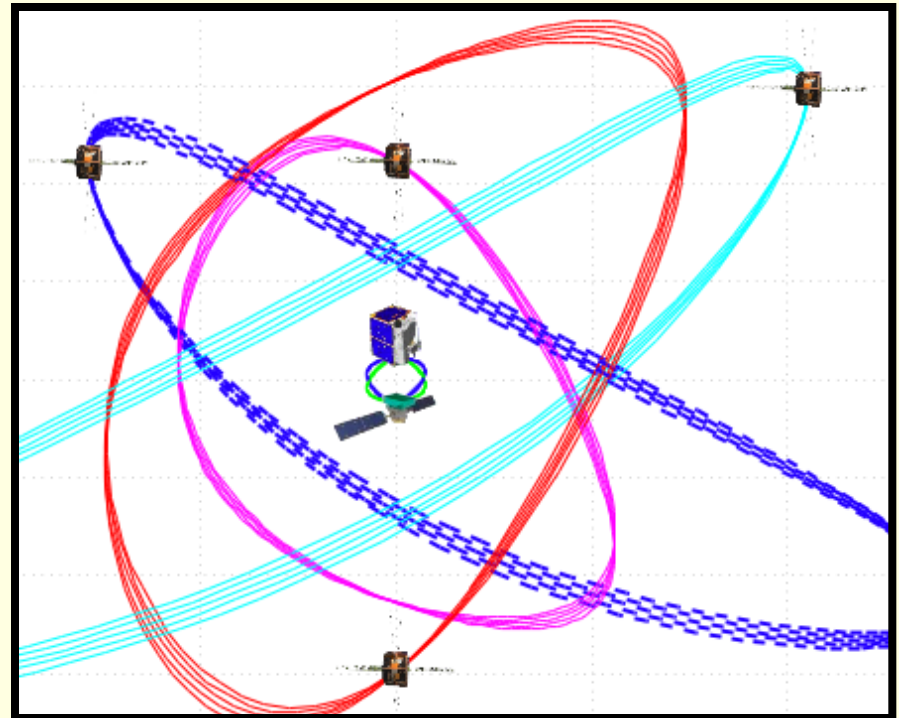
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Fractionated Spacecraft



- Replace “monolithic” satellite with multiple free-flying modules
- Capabilities
 - Extend and enhance ongoing missions
 - Replace failed components
 - Survive module failure
 - Spatially distributed sensing
- Requirements
 - Coordinated Navigation
 - Distributed Operations
 - ***Inter-module Communication***



Communications for Fractionated Spacecraft



■ Challenges

- Wide variation in distances between modules
- Limitations on size, weight, and power
- Space-qualified, radiation-tolerant hardware
- Regulatory approval for use of radio spectrum

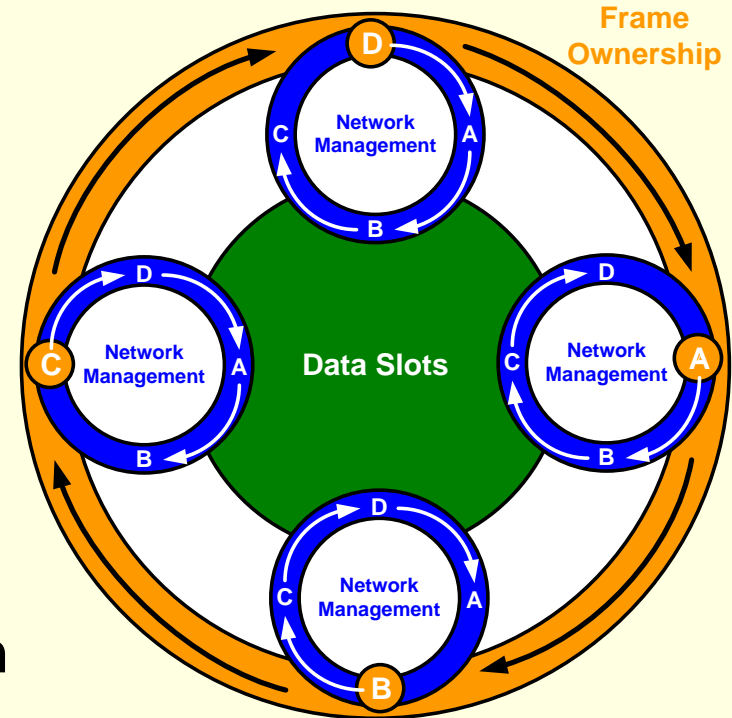
■ Desirable Characteristics

- Predictable Performance: Throughput, Latency
- Efficient use of data communications capacity
- Robust tolerance to loss of any module
- Inter-module distance estimation
- Distribution of a common precision timing reference

F6WICS: TDMA Burst Communications System



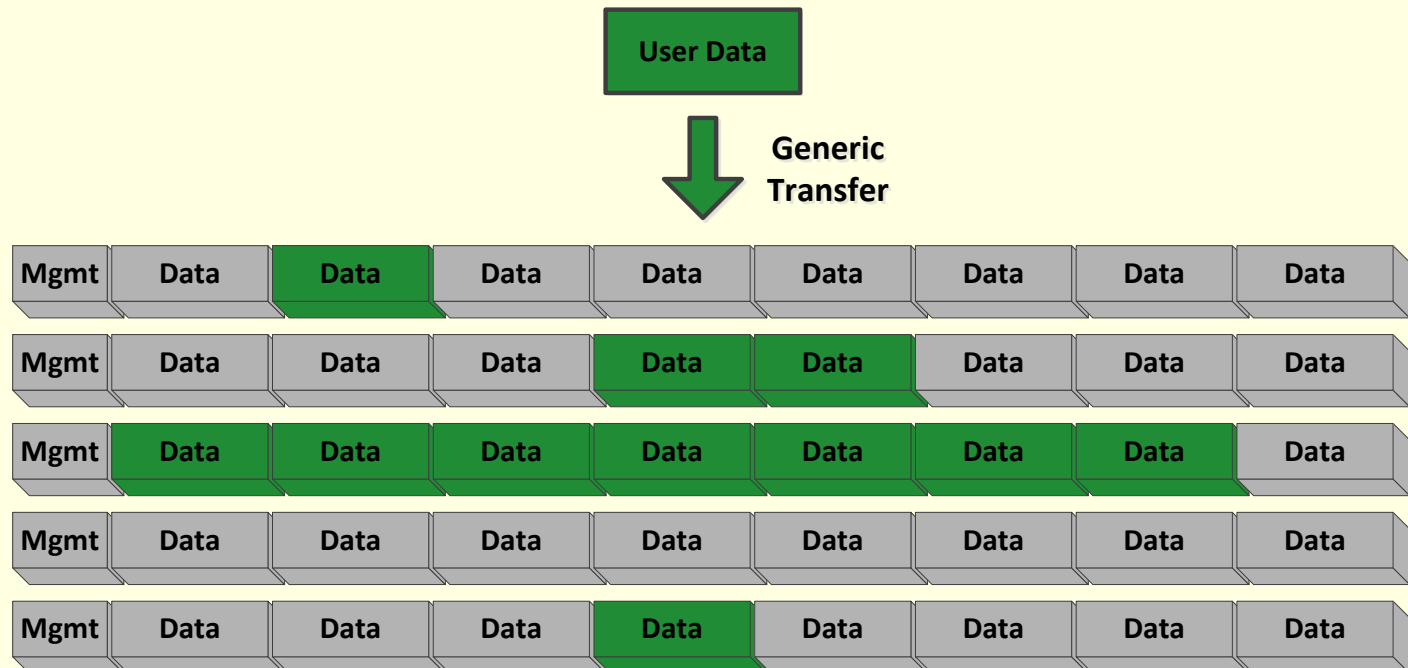
- TDMA Channel Access
 - Efficient use of capacity
 - Predictable latency and throughput
 - No contention for channel
- Fully Distributed Link Coordination
 - Robust to loss of any node
 - On-demand resource allocation
 - Three data transfer mechanisms





Generic Transfers

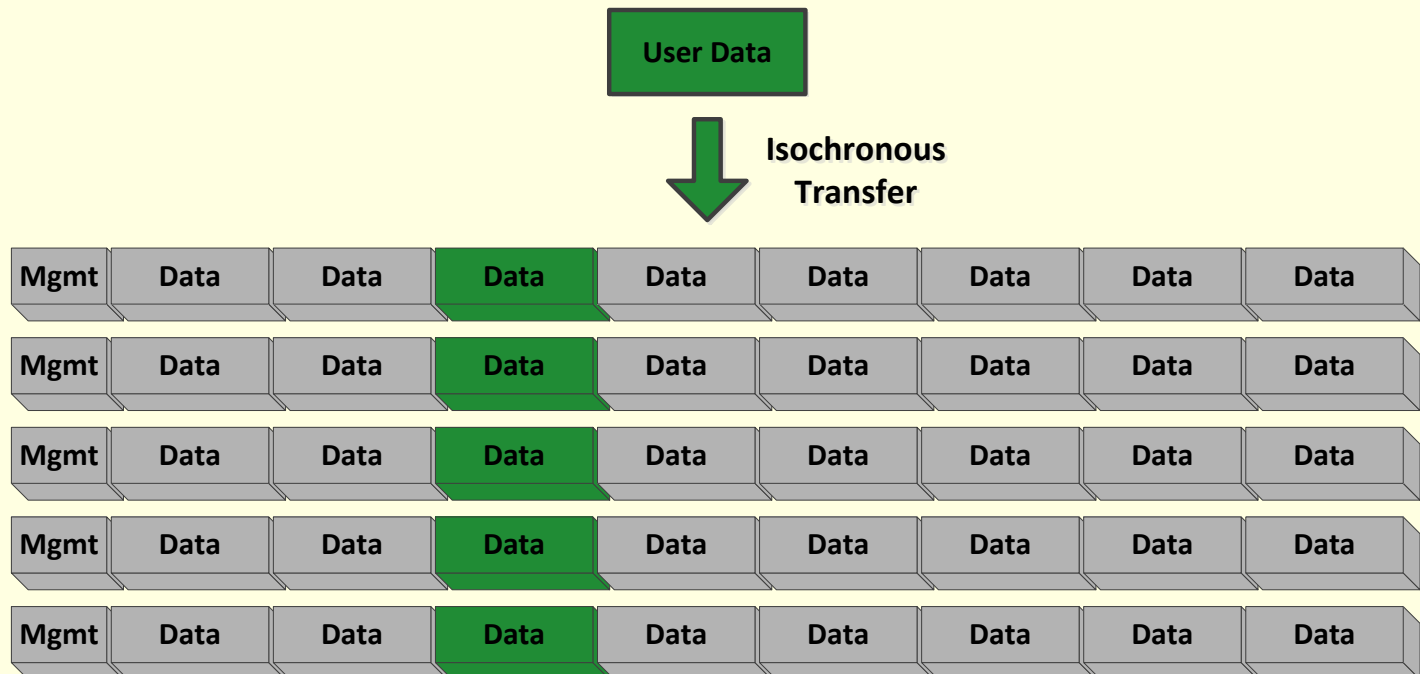
- Best effort transfer
- Utilizes all capacity not allocated to other transfer mechanisms
- Multicast at physical layer
- Generally highest throughput transfer mechanism
- No latency guarantees
- Bulk data transfers





Isochronous Transfers

- Long-term capacity reservation
- Guaranteed latency
- Precisely scheduled data delivery
- Streaming data
- Distributed control loops
- Periodic data with strict latency requirements



Physical Layer Waveform



- Wideband Direct Sequence Spread Spectrum (DSSS) Burst Waveform
- Scalable data rate changes with distance
- Requires precision time synchronization between transmitter and receiver
- Specialized code synchronization algorithm enables rapid synchronization and extended tracking between frames
- Capabilities Enabled by Code Synchronization
 - Estimation of range between radios
 - Precision time transfer

Supporting Services

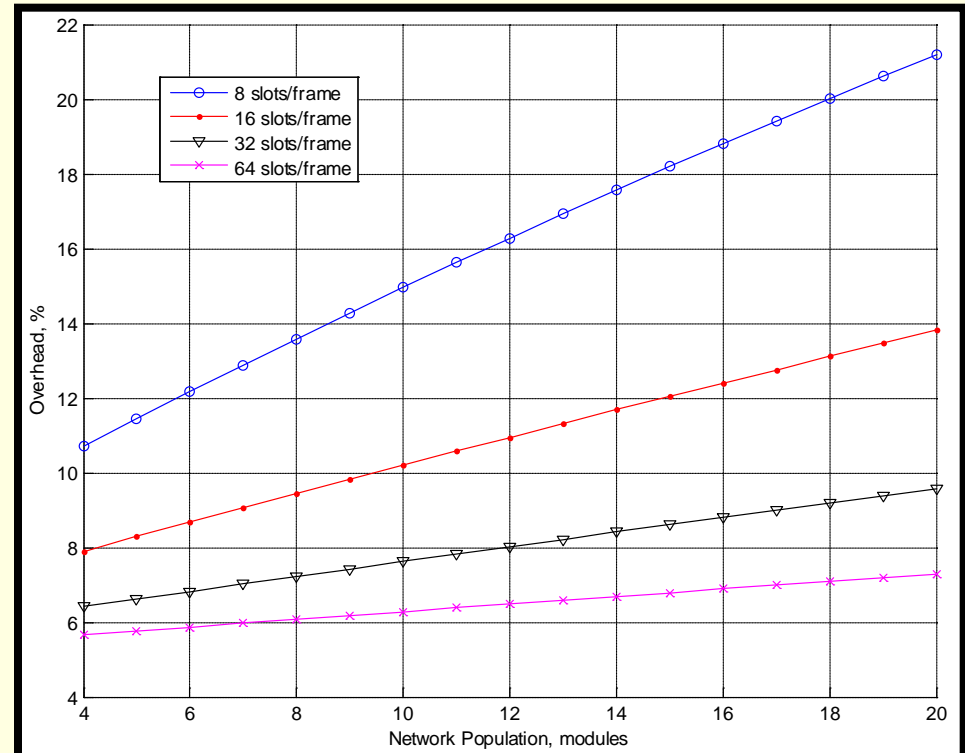


- Inter-module Range Estimation
 - Utilize physical layer mechanisms to estimate distance between modules
 - Independent of GPS
 - Resolution of ± 6 meters sufficient for navigation
 - Ranges disseminated throughout network
- Common Timing Reference Distribution
 - Utilizes physical layer mechanisms to establish coordinated, distributed timing reference
 - Timestamp range measurements, data transfers
- Link Layer Topology Monitoring
 - Monitor and report local inter-module connectivity to two hops



Overhead Analysis

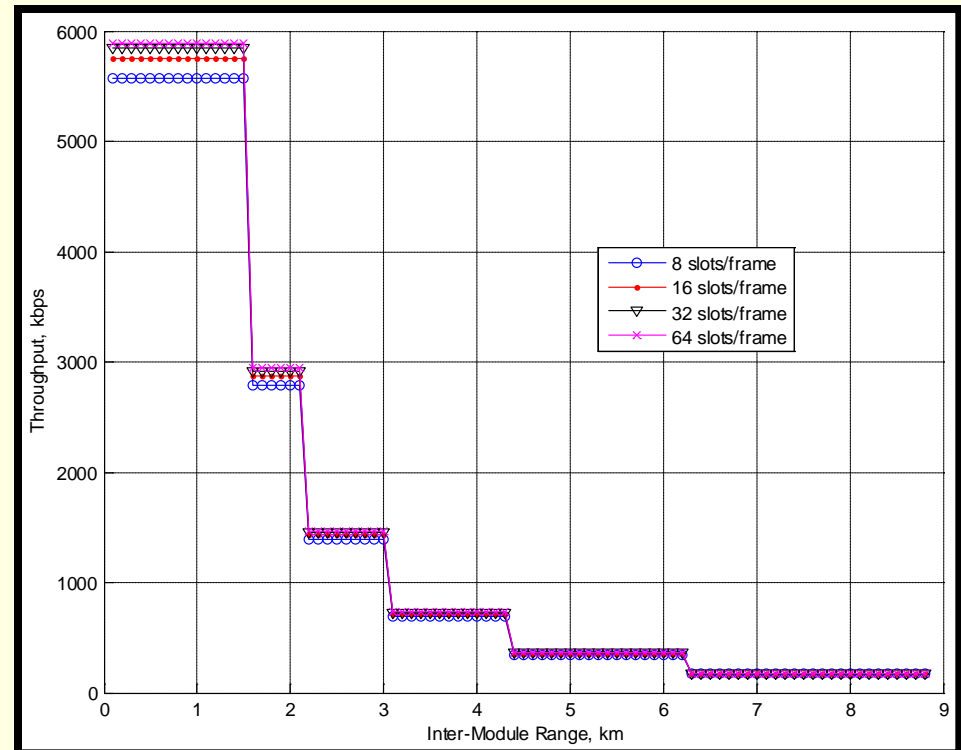
- Configuration Parameters
 - Population
 - Data slots per frame
 - Latency / Throughput
 - Max operational range
 - Range / Overhead
 - 8.9 km operational range for this data
- TDMA implies deterministic overhead
- “Overhead” is *all* time not spent sending user payload data



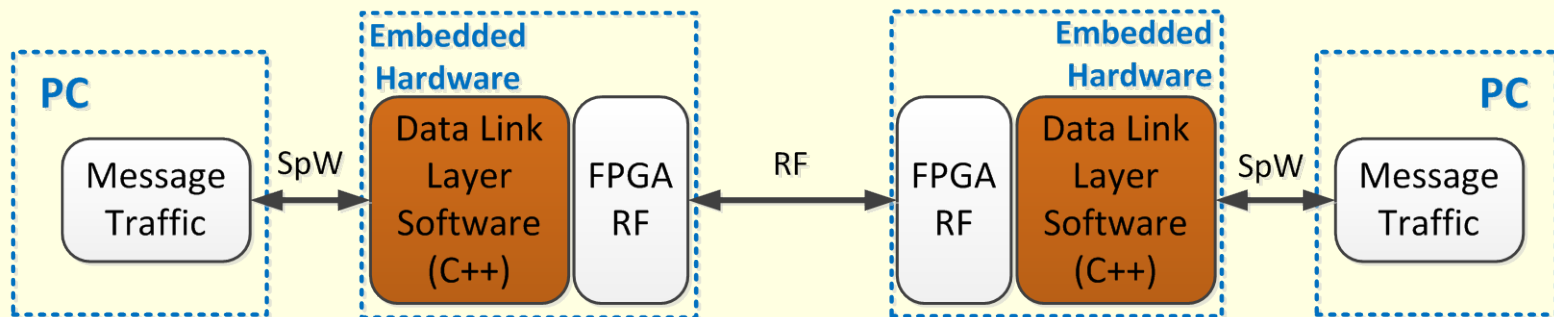
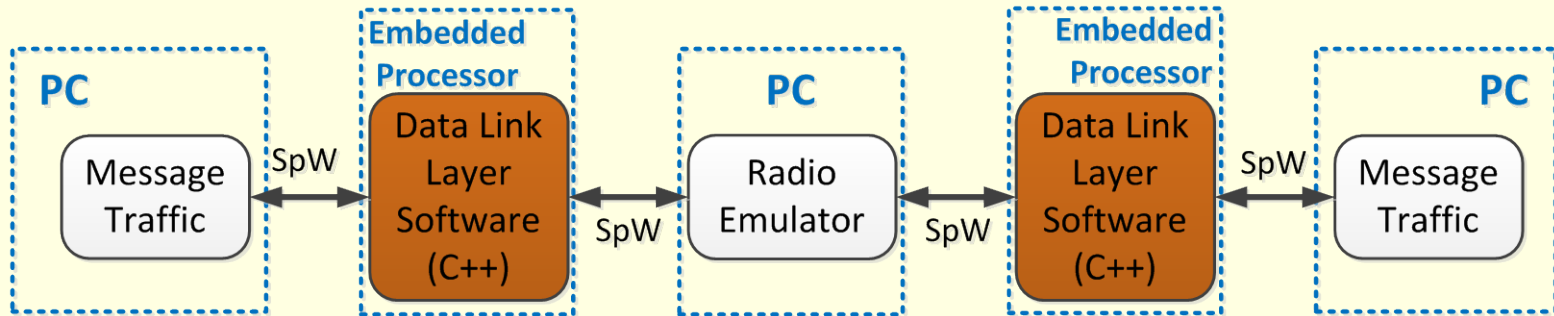
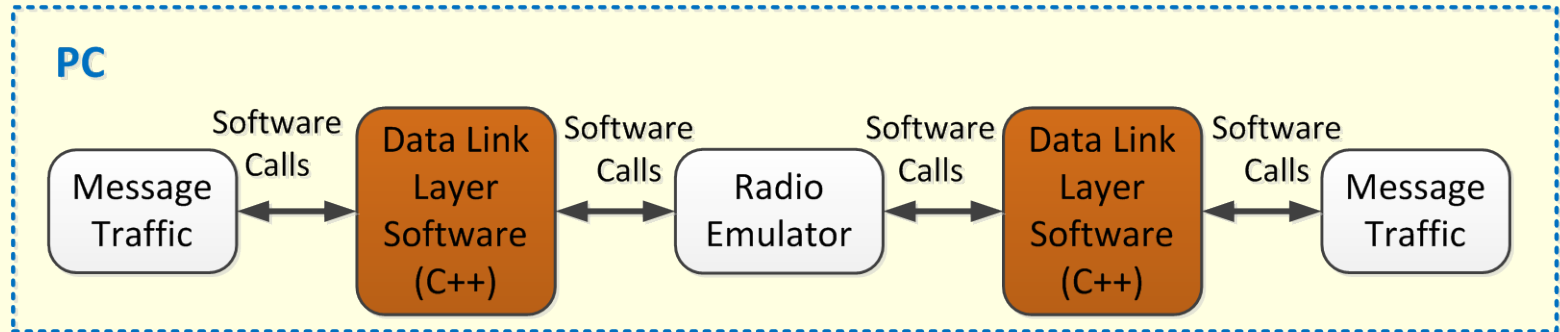
Throughput Analysis



- User data rate automatically scales with distance between communicating modules
- Data rate set by most distant addressee in multicast
- “Throughput” is total user data capacity



Iterative Software Development



Conclusions and Future Work



- F6WICS is a communications system tailored to the specific needs of fractionated spacecraft
- Three distinct data transfer mechanisms provide *guaranteed* communications characteristics at the data link and physical layers
- Physical layer mechanisms provide supporting services for navigation and distributed operations
- Design is now being implemented on terrestrial prototype hardware
- On-orbit demo mission planned

Acknowledgements



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