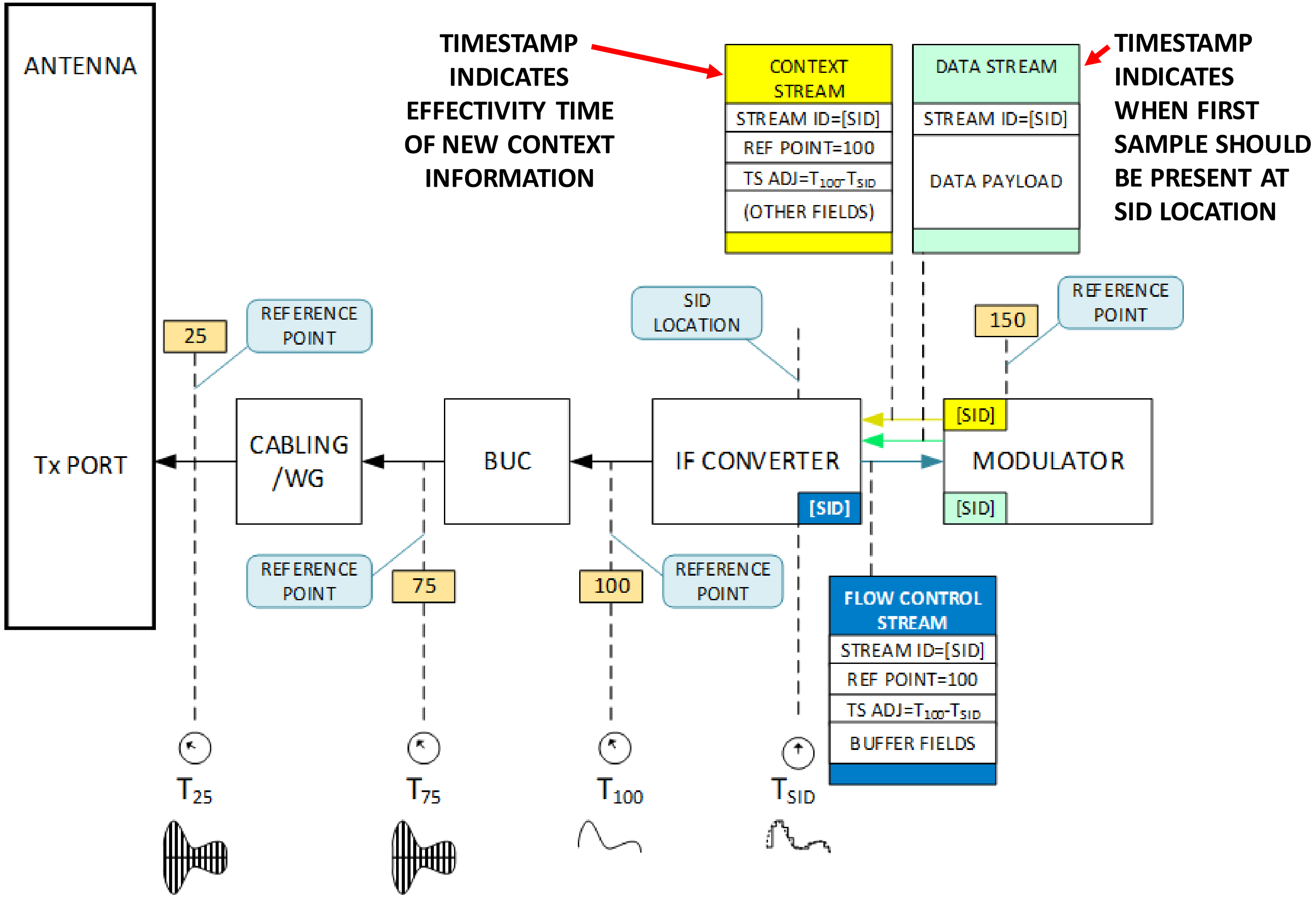
Using the DIFI Protocol with Time-Division Multiple Access, Multi-Frequency TDMA, and Frequency-Hopped Spread Spectrum Transmissions

MILCOM DIFI Workshop, October 28, 2024

Jim Rosenberg, Integrated Solutions Architect, Wavestream Corporation
jim.rosenberg@wavestream.com

Key Requirements for TDMA, MFTDMA, and FHSS Transmission

- Time Division Multiple Access (TDMA), Multi-Frequency TDMA, and Frequency Hopped Spread Spectrum transmissions all use “burst” transmission
- One key requirement for all three transmission types is the need for timing accuracy of the bursts (timing of the release of samples from the converter’s buffer to the DAC)



Key Requirements for TDMA, MFTDMA, and FHSS Transmission

- For MFTDMA and FHSS, there is also the requirement that successive bursts be transmitted at different frequencies, and especially with HFSS, the "hop periods" can be quite short (as little as tens of microseconds)

- For successful application of digital IF, the system must be configured for adequate timing accuracy and the frequency agility required by the use case

- In order to use DIFI for MFTDMA or FHSS, the system designer must:
  - identify the synchronization configuration to determine which Information Class and implementation should be used
  - select frequency hopping implementation – DIFI Source-implemented in the digital domain versus Sink-implemented based on
    - Frequency hop dynamics (available inter-burst dead time, if any)
    - Hopping bandwidth and DAC cost

Sample Rate Synchronization and Timing Accuracy

- All DIFI use cases require synchronization of DIFI Source and Sink sample *rates*, to avoid buffer over/underflow
- TDMA/MFTDMA/FHSS also require accuracy in the timing of the burst transmissions, requiring the Source and Sink to also have some degree of “time-of-day” alignment with an external reference
- Therefore, TDMA/MFTDMA and FHSS system designers must consider how their system will accomplish:
  - Sample Rate synchronization between DIFI Source and Sink
  - Time of day alignment with some reference outside the Source/Sink pair, e.g.:
    - TDMA hub clock
    - FHSS link counterpart
    - Time-of-Day reference such as GPS/GNSS

Sample Rate Synchronization and Timing Accuracy

Sample Rate synchronization can be achieved by several means:

- Shared external reference (e.g., 10MHz reference signal)
- DIFI Packet based synchronization*
  - Average arrival rate and timestamps of Data Packets
  - Use of Flow Control Packets (DIFI v1.2.0 and later)

*This was described at last year's workshop by Brian Olson

Time of Day Alignment Options

- If an external reference, such as GPS/GNSS, is available, the DIFI Source and Sink "internal clocks" can be set to this external reference
- In many TDMA/MFTDMA systems, the remote terminals are synchronized to a time-of-day reference at the hub – which need not be especially accurate with respect to "actual" time-of-day*
- In FHSS systems, the receiver and and transmitter are often time-synchronized through the signal itself on a per-session basis with no reference to actual time-of-day

*This is different from 5G eCPRI/O-RAN systems, where synchronization of all terminals to a shared time-of-day reference

Time of Day Alignment Options

In many TDMA/MFTDMA systems:

- A remote terminal bursts onto the network with a “sloppily timed” burst
- The hub modem signals to the remote modem (through the forward path) by how much it should either advance or retard its transmission burst timing to with the hub clock
- In legacy analog systems, the delay between the issuance of the signal by the modem and the transmission time is fixed … in a digital IF system the modem can regulate the transmission time through the Data Packet timestamps, provided modem and DIFI Sink rates are synchronized

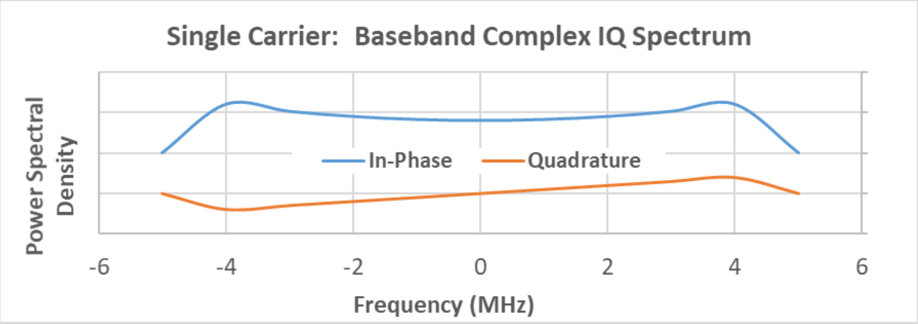
Time of Day Alignment Options

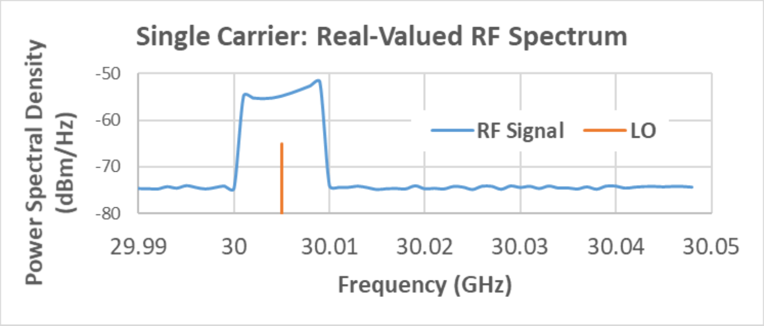
In some FHSS systems, time alignment between the satellite uplinker and the downlink receiver is carried on a “per session” basis

- Uplinker transmits a known data pattern through one or more (secret) full hop sequence(s)
- Downlink receiver uses correlation of received signal with secret hop sequence and known data pattern to align receiver hop sequence timing with transmitter hop sequence timing

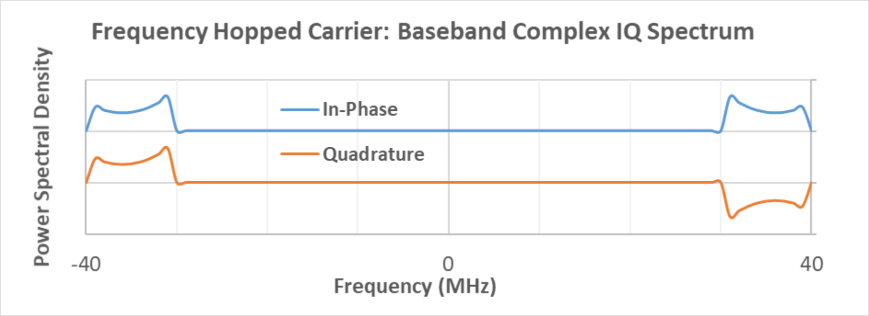
DIFI Tx Frequency Representation Alternatives & Implications

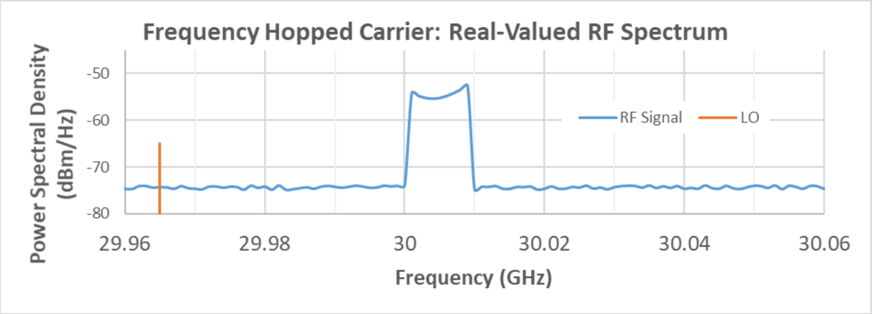
- Imagine one wants to transmit a 10MHz wide carrier at a center frequency of 30.005 GHz … there are two means of representing this in a DIFI Stream:
  a. Represent the signal data at Zero IF in the Data Payload, and set the RF Reference Frequency to 30.1GHz





  b. Represent the signal data at an offset from Zero IF (e.g., at 100MHz), and set the RF reference frequency to the difference between this offset and the desired RF center frequency (e.g., 30GHz)



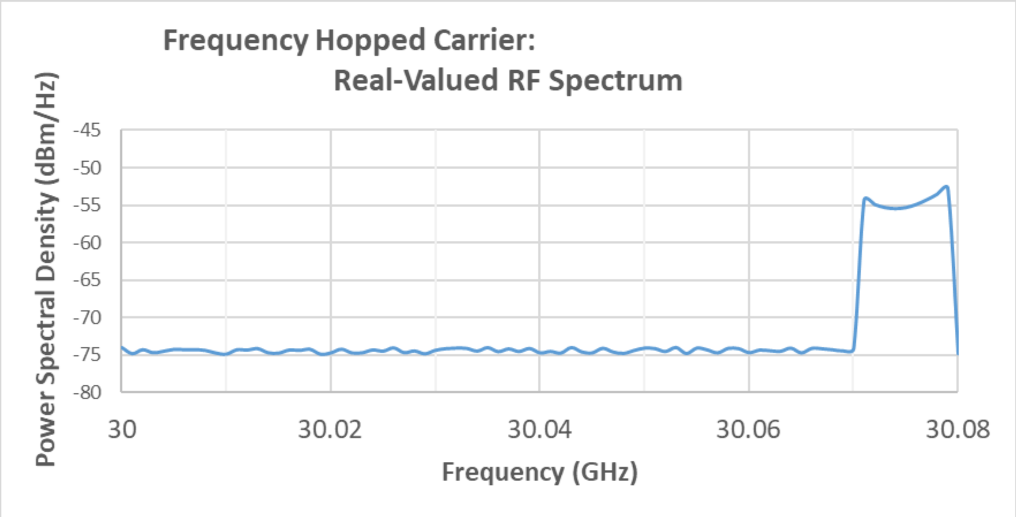


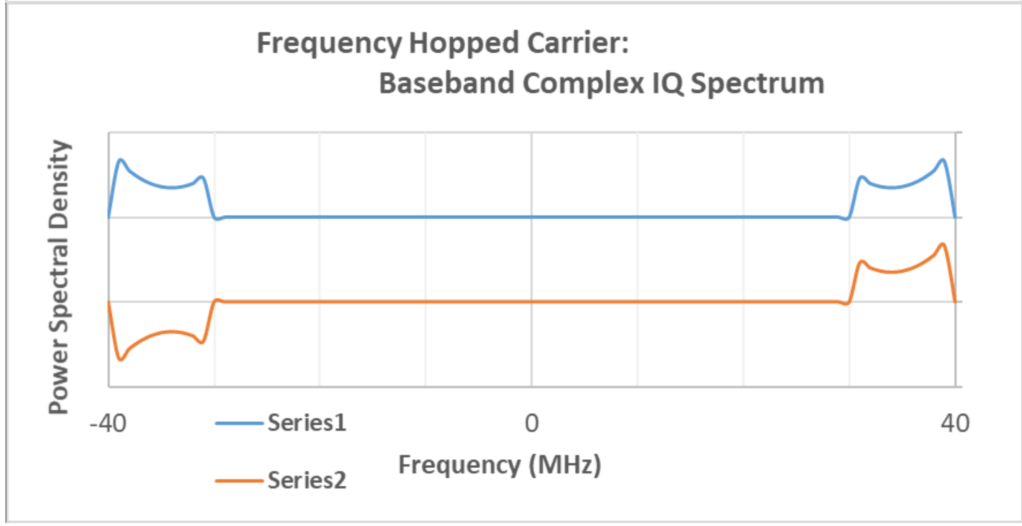
Visualization of Frequency Hopping in Digital IF with Fixed LO

- For applications in which there is little or no dead-time between frequency-hopped bursts, representation "b" from the previous slide is preferable

- The LO frequency can be fixed, and the representation of the signal is "hopped" in the digital domain

- This digital hopping
  - can be essentially instantaneous
  - does not require that the DIFI Sink have any knowledge of the frequency hop sequence





DIFI Tx Frequency Representation Alternatives & Implications

- Using approach (a), changing the frequency of a successive burst involves
  - changing the RF Reference Frequency (or IF Reference Frequency) value on a burst-by-burst basis in the Context Packets
  - retuning the frequency translation in the RFC/IFC on a burst-by-burst basis*
- Using approach (b)
  - the Reference Frequency is not changed throughout the transmission
  - the signal frequency is "hopped" in the digital domain within the Data Payload

*DIFI protocol requires that Context information remain fixed throughout a Data Packet, so each new burst must begin with a fresh Data Packet sharing a timestamp with the new Context Packet

Digital IF Representation Alternatives & Their Implications

- Therefore, there are two approaches to "hopping" the RF carrier center frequency:
  - Represent the signal at zero IF, and reset the Local Oscillator (LO) frequency for each hop
  - Hold the LO frequency constant, and hop the digital representation of the signal

	Pro's	Con's
Signal always at Zero IF	DAC sample rate set by individual carrier bandwidth (less expensive)	Required dead-time between bursts to change LO frequency
Signal frequency hopped in digital representation	Transmit frequency can be changed nearly instantaneously	Digital-to-Analog conversion sample rate set by full hopping bandwidth (more expensive)

- In MFTDMA each remote is generally afforded some dead time between bursts (as the network services other remotes), making the less expensive Zero IF approach practical
- In FHSS, short hop periods with essentially continuous transmission from hop-to-hop, coupled with desire to avoid having sequence information at the antenna, makes hopping the transmission in the digital domain (at the modem) preferable

Packet Representation of Burst Data

- In TDMA and MFTDMA, data transmission to the satellite is discontinuous, with "in burst" transmission periods and "out of burst" periods of no RF transmission
- There are two categories for representing this in DIFI packets:
  A. Continuous packet transmission, with "out of burst" segments represented by "idle samples" (I=0, Q=0) in the data payload
  B. Discontinuous (burst) DIFI Data Packet transmission, with DIFI Data Packets sent only when there is data for the satellite
  - Provided that there is no significant cost for traffic on the digital IF transport – e.g., in an airborne terminal in which the digital IF line is a dedicated fiber – implementation A is simpler
  - If traffic on the digital IF line has significant marginal cost – e.g., a public WAN paid for by the bit transferred – and the out-of-burst times are significant, implementation B may be preferred despite the additional complexity

Use Cases, Based on Reference Availability, Hopping Approach, and DIFI Data Packet Flow

There are five categories identified, which fit into four Packet Stream implementations:

(a) Reference Plane Present,

- Continuous DIFI Data Packet Stream, using Idle Samples for out-of-burst periods (Use Case 1.B)
- Discontinuous DIFI Data Packet Stream, corresponding to Satellite transmission bursts (Use Case 1.B)

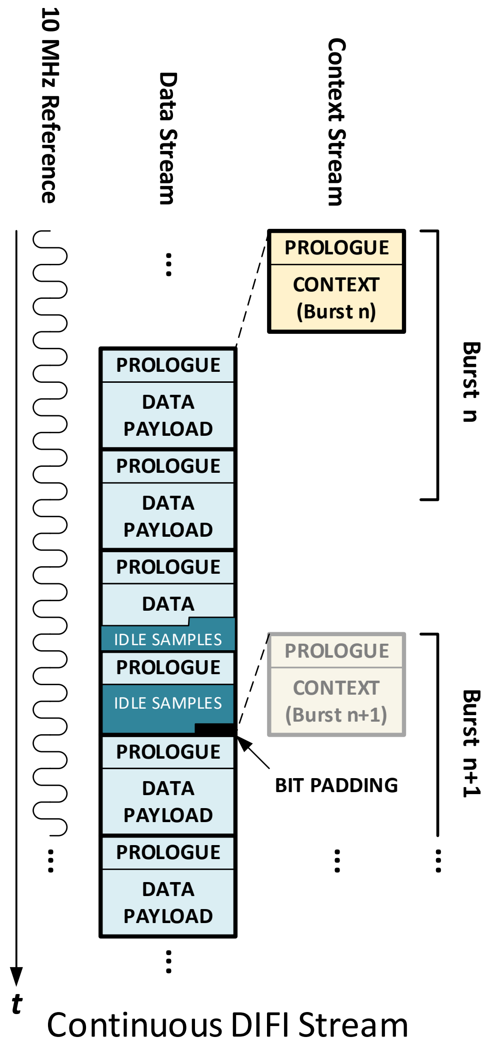
(b) No Reference Plane Present

- DIFI Source is Sample Rate Master
  - Continuous DIFI Data Packet Stream with idle samples (Use Case 2.A.1)
  - Discontinuous (bursted) DIFI Data Packet Stream (Use Case 2.A.2)

(c) DIFI Sink is Sample Rate Master, either continuous DIFI Data Packet Stream with idle samples or discontinuous DIFI Data Packet Stream (Use Case 2.B.2)

Reference Plane Present, Source and Sink are Synchronized Through Ref Plane (e.g., 10MHz Reference), Continuous Packets, Info' Class 0x0000 or 0x0004

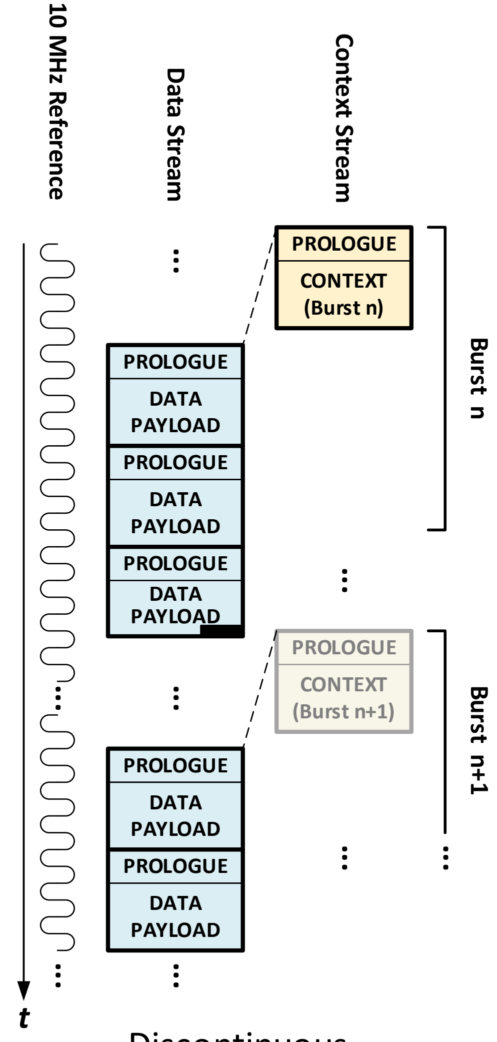
- Diagram at right shows DIFI Source sending Data Packets continuously, filling the data payload with idle samples (I=0, Q=0) when the satellite transmission is out of burst
- If Context is changing burst-by-burst (hopping implemented at the Sink), the DIFI source prepares and sends Context Packet characterizing associated burst parameters at the earliest available time
- The timestamp on a Context Packet represents the "effectivity time" of the new parameters
- If frequency hopping is implemented at the DIFI Source, new Context Packets are not needed for each new burst if bandwidth and Reference Level are unchanged
- Padding of the Data Payload must then be permitted, since the number of samples (active plus idle) between the first sample of one burst and the first sample of the following burst may not fit into an integer number of 32-bit words



Continuous DIFI Stream with Idle Samples

Reference Plane Present, Source and Sink are Synchronized Through Ref Plane (e.g., 10MHz Reference),Bursted Data Packets, Info' Class 0x0000 or 0x0004

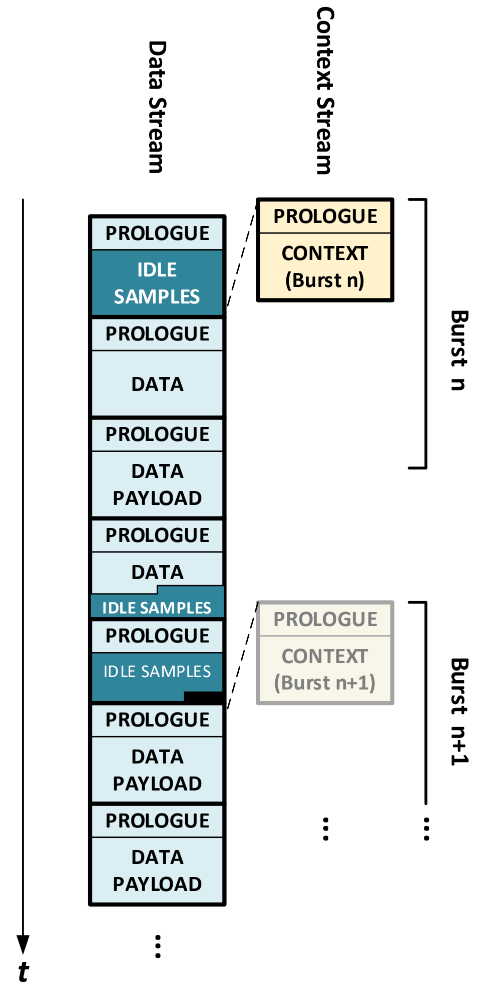
- At right, DIFI Source sends Data Packets discontinuously, matching satellite Tx bursts
- If Context is changing burst-by-burst (hopping implemented at the Sink), the DIFI source prepares and sends Context Packet characterizing associated burst parameters at the earliest available time
- The timestamp on a Context Packet represents the "effectivity time" of the new parameters
- If frequency hopping is implemented at the DIFI Source, new Context Packets are not needed for each new burst if bandwidth and Reference Level are unchanged
- Padding of the Data Payload must then be permitted, since the number of samples (active plus idle) between the first sample of one burst and the first sample of the following burst may not fit into an integer number of 32-bit words



Discontinuous DIFI Stream

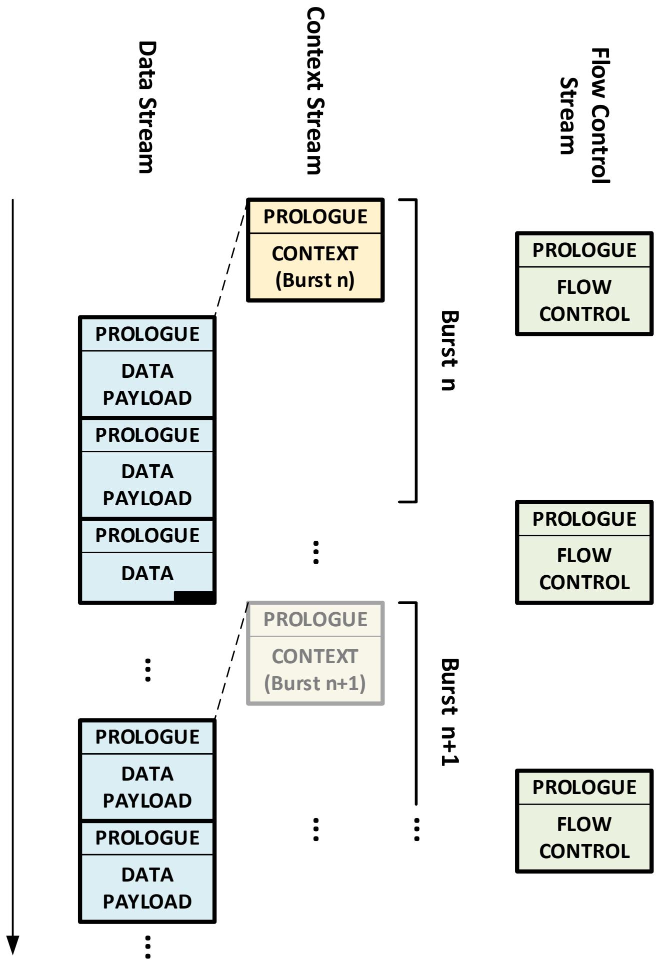
No Reference Plane, DIFI Source is Sample Rate Master, Continuous Data Packet Stream, Info' Class 0x0000 or 0x0004

- DIFI Source continuously issues Data Packets, filling the "out of burst" time intervals with "idle samples" (I=0, Q=0)
- DIFI Sink synchronizes its sample rate to the DIFI Source sample rate by averaging arrival rate of samples
- If Context is changing burst-by-burst (hopping implemented at the Sink), the DIFI source prepares and sends Context Packet characterizing associated burst parameters at the earliest available time
- The timestamp on a Context Packet represents the "effectivity time"
- Padding of the Data Payload must then be permitted, since the number of samples (active plus idle) between the first sample of one burst and the first sample of the following burst may not fit into an integer number of 32-bit words



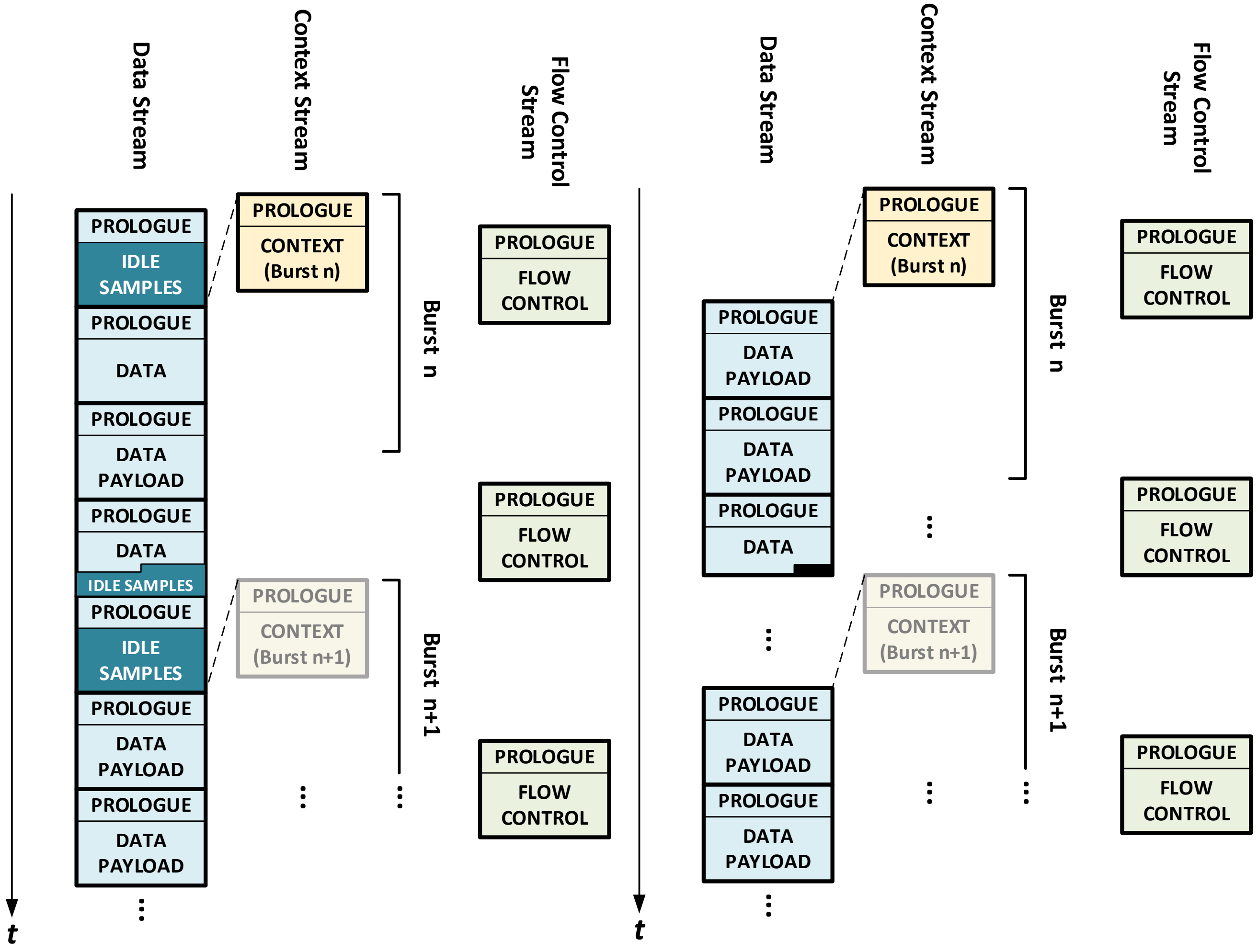
No Reference Plane, DIFI Source is Sample Rate Master, Bursted Data Packets, Info' Class 0x0002 or 0x0003

- DIFI source sends packets only when there is satellite transmission data (TDMA burst)
- Sample Rate synchronization using Flow Control Packets directed from Source to Sink
- If Context is changing burst-by-burst (hopping implemented at the Sink), the DIFI source prepares and sends Context Packet characterizing associated burst parameters at the earliest available time
- Context Packet bears Timestamp of effectivity time of the new parameters, that is, at the time that the first data sample in the first Data Packet of the burst should be present at the SID location
- Padding of the Data Payload must be permitted



Use Case 4: No Reference Plane, DIFI Sink is Rate Master, Continuous or Discontinuous Digital Stream, Info' Class 0x0002 or 0x0003

- DIFI Source continuously issues Data Packets, figure at left; or issues Data Packets discontinuously, figure at right
- DIFI Source synchronizes its sample rate to the DIFI Sink sample rate by averaging arrival rate of Flow Control Packets (flowing "upstream" from Sink to Source)
- If Context is changing burst-by-burst (hopping implemented at the Sink), the DIFI source prepares and sends Context Packet characterizing associated burst parameters at the earliest available time
- The timestamp on a Context Packet represents the "effectivity time"
- Padding of the Data Payload must then be permitted



Continuous DIFI Stream with Idle Samples

Discontinuous DIFI Stream

Summary

- TDMA, MFTDMA, and FHSS can be supported using Information Class 0x0000* (v1.1, v1.2) if DIFI Source and Sink share a common reference plane, or if the DIFI Source is the Sample Rate master and the Data Packet Stream is continuous
- TDMA, MFTDMA, and FHSS can be supported using Information Classes 0x0002 or 0x0003 (v1.2) if the DIFI Source is Sample Rate Master and the Data Packet Stream is discontinuous, or if the DIFI Sink is the Sample Rate master.
- System designer must identify the synchronization configuration to determine which Information Class and implementation should be used
- System designed must select frequency hopping implementation – DIFI Source-implemented in the digital domain versus Sink-implemented based on
  - Frequency hop dynamics (available inter-burst dead time, if any)
  - Hopping bandwidth and DAC cost

*Will also be supported by Info' Class 0x0004 in v1.2.1 and later versions, which will be a Sample