ARTS Interface Specification from BF to SC3+4

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Document History:

Revision	Date	Author	Modification / Change
0.1	2015-12-02	Roy Smits	SC1 interface document.
0.2	2015-12-14	Alessio Sclocco	First draft of SC4 interface.
0.3	2016-01-27	Alessio Sclocco	Update of the packet structure.
0.4	2016-01-29	Alessio Sclocco	Added a description of the flags.
0.5	2016-02-05	Alessio Sclocco	Added data rates for SC3.
1.0	2016-02-18	Alessio Sclocco	Review by E. Kooistra and D. van der Schuur.
2.0	2017-02-10	Alessio Sclocco	Update of the interface between the ARTS BF and the SC4 pipeline.

Summary:

This document describes the interface specifications for ARTS Science Case 3 and 4 (SC3+4). It contains a description of the hardware setup, the content of the Ethernet packet and the required data rates for real-time processing.

Contents

1 Introduction

Science cases 3 and 4 (SC3+4) consist on the real-time detection of fast radio bursts (FRBs), and the discovery of new pulsars; the difference between the two science cases is that SC3 is a commensal search, while SC4 is a dedicated one. To operate, the software pipeline (PL) responsible for SC3+4 needs to acquire its input from the ARTS beam former (BF); the ARTS BF is described in [1]. The input consists of 37 compound beams (CB), each of them composed by 12 tied-array beams (TABs) or 11 TABs and 1 incoherent beam (IAB). Each TAB is made up of 1536 frequency channels, and 25000 samples per time interval in SC4, or 12500 samples per time interval in SC3; a time interval is defined as 1.024 seconds. A sample represent either the Stokes I or the Stokes IQUV of the measured electromagnetic signal. Once the input is transferred from the ARTS BF to the SC3+4 subsystem, it is processed in real-time to detect FRBs, and at the same time stored to disk for the periodicity search.

2 Hardware Setup

The Apertif hardware at the dishes outputs 37 CBs per dish. The Arts BF coherently combines the CB signals from the dishes, and creates 12 TABs per CB, for all 37 CBs. The ARTS BF runs on 16 UniBoards for SC4 and on 4 UniBoard^2 for SC3. The Arts BF outputs the TABs to the Arts PL. The Arts PL use 37 GPU workstations and is described in detail in [2]. Each workstation processes the TABs for one CB. The interface between the Arts BF and Arts PL consists of a set of 10/40GbE switches. Via this interface the frequeny channels are aggregated per CB.

3 Content of the Ethernet Packet

The communication between the BF and the SC3+4 PL relies on the User Datagram Protocol (UDP) as a transport layer. Each Ethernet packet transmitted by the BF contains, together with all network related information, two application components, header and payload.

Table 1: Overview of the fields in the Ethernet packet, including the size in bytes of each field, and endianness.

Field	Size (bytes)	Endianness
Interpacket gap	12	big
ETH preamble + SFD	8	big
ETH header	14	big
IPv4 header	20	big
UDP header	8	big
Application header	48	big
Application payload (Stokes I)	6250	—
Application payload (Stokes IQUV)	8000	—
ETH CRC	4	big

The total size of a network packet is 6364 bytes for the Stokes I packets, and 8114 bytes for the Stokes IQUV packets; in both cases the overhead (i.e. Ethernet and application headers) amounts to 114 bytes. Application header and payload are described in detail in Section 3.1 and Section 3.2, respectively.

3.1 Application Header

The application header contains all the information necessary to interpret the payload; Table 2 lists the fields of the header, and shows their size (in bytes), the origin of the information, and the endianness. This header precedes the application payload in the network packet.

Table 2: Overview of the fields in the application header, including the size (in bytes), origin of the information, and endianness.

Field	Size (bytes)	Origin	Endianness
Marker Byte	1	Apertif BF	big
Format Version	1	ARTS BF	big
CB Index	1	ARTS BF	big
TAB Index	1	ARTS BF	big
Channel Index	2	ARTS BF	big
Application Payload Size	2	ARTS BF	big
Timestamp	8	ARTS BF	big
Sequence Number	1	ARTS BF	big
Reserved	7	ARTS BF	big
Flags	24	Apertif BF + ARTS BF + MAC	big

The **Marker Byte** field is generated by the Apertif BF and contains an unsigned integer number that marks the beginning of the UDP payload. The values, hexadecimal integer numbers, are described int Table 3. The **Format Version** field is generated by the ARTS BF and contains the version of the protocol used for communicating between the BF and the SC3+4 PL; the version described in this document is version "1" of the protocol. The **CB Index** field is generated by the ARTS BF and contains an unsigned integer number (between 0 and 36) that identifies the CB the data is associated with. The **TAB Index** field is generated by the ARTS BF and contains an unsigned integer number (between 0 and 11) that identifies the TAB the data is associated with. The combination of the two fields, CB and TAB, uniquely identifies the beam the data is associated with. The **Channel Index** field is generated by the ARTS BF and contains an unsigned integer number (between 0 and 1535) that identifies the frequency channel the data is associated with. In Stokes IQUV mode, where each packet contains 4 channels, this field identifies the index of the first of these four channels. The **Application Payload Size** field is generated by the ARTS BF and contains an unsigned integer number that represents the number of bytes that the application payload containes; this number is either 6250 for Stokes I packets, or 8000 for Stokes IQUV packets. The **Timestamp** field is generated by the ARTS BF and contains an unsigned 64 bit integer number; this number represents the number of units of 1.28 μs that have elapsed since the midnight of the 1st of January 1970. The **Sequence Number** field is generated by the ARTS BF and contains an unsigned integer number. The value of this field for SC4 is between 0 and 3 for Stokes I, and between 0 and 49 for Stokes IQUV, while for SC3 is between 0 and 1 for Stokes I, and between 0 and between 0 and 24 for Stokes IQUV. This field is used to reorder the packets that are associated with the same time interval. The **Reserved** field is 7 bytes long and it is reserved for use in future versions of this format; its current purpose is to keep the application header a multiple of 8 bytes after the introduction of the "Sequence Number" field. The **Flags** field is generated by the Apertif and ARTS BF, and the management and control (MAC) system, and contains the fields described in Table 4. For each flag[23:0] the bytes are transmitted in big endian order: [23:16],[15:8],[7:0]. The flags [11:0] represent the X polarization from dish [11:0] and flags [23:12] represent the Y polarization input from dish[11:0]. The dish indices 0:11 are mapped to WSRT dishes RT-2,3,4,5,6,7,8,9,A,B,C,D. The total size of the packet header is 48 bytes.

3.2 Application Payload

The application payload consists in a sequence of 6250 unsigned 8 bit integer values in Stokes I packets, or a sequence of 8000 signed 8 bit integer values in Stokes IQUV packets. Information about the CB, TAB, and channel

Table 3: Semantic of the Marker field.

Value	Meaning
0xD0	SC3 Stokes I with TAB data
0xD1	SC3 Stokes IQUV with TAB data
0xD2	SC3 Stokes I with IAB data
0xD3	SC3 Stokes IQUV with IAB data
0xE0	SC4 Stokes I with TAB data
0xE1	SC4 Stokes IQUV with TAB data
0xE2	SC4 Stokes I with IAB data
0xE3	SC4 Stokes IQUV with IAB data

Table 4: Overview of the Flags field, including the size (in bytes), and endianness.

Field	Size (bytes)	Endianness
crc_error	3	big
no_input_present	3	big
uploading_weights	3	big
noise_source_enabled	3	big
telescope_pointing_off	3	big
antenna_broken	3	big
reserved_0	3	big
reserved_1	3	big

associated with each sample is contained in the application header. The time, in seconds, associated with each sample can be computed using the information in the "Timestamp" and "Sequence Number" headers by applying the following formulas:

- **Stokes I**: *time = Timestamp + (((SequenceNumber * 6250) + Index) * 1.28)*
- **Stokes IQUV**: *time = Timestamp + (((SequenceNumber * 500) + (Index / 16)) * 1.28)*

In Stokes I packets the payload contains a single dimension, time, so successive bytes represents successive time samples. Therefore, in this mode the payload is an array of 6250 Stokes I elements between t_0 and t_{6249}. In Stokes IQUV packets the payload contains three dimensions: (1) time, (2) channel, and (3) Stokes. In this mode the payload is an array of 8000 elements, with 500 time intervals between t_0 and t_{499}, each containing 4 channels, between c_0 and c_3, and with each channel containing the four IQUV Stokes between s_0 and s_3.

4 Data Rates

The size of each network packet sent by the BF to the PL for SC4 is 6364 bytes for Stokes I packets, and 8114 bytes for Stokes IQUV packets. Considering that for SC4, the larger of the two science cases, each time interval is represented by 25000 samples, a total of 4 Stokes I and 50 Stokes IQUV packets is required to transfer all the data from the BF to the PL for a time interval. For each time interval there are 2727936 Stokes I packets, and 8524800 Stokes IQUV packets, for a total of 11252736 packets, therefore the data rate for the whole system is therefore of 10989000 packets per second, or 297000 packets per second per server. The total amount of bytes transferred per second is 86530811904, therefore the data rate for the whole system is 84.5 GB/s, or 2.3 GB/s per server. For what concerns SC3, the lower time resolution and lower number of TABs means that the data rates for SC4 are 2.6 times less, therefore the data rate for the whole system is 32.5 GB/s, and the data rate for each server is 0.88 GB/s.

References

[1] Eric Kooistra. Detailed Design of the ARTS FPGA Beamformer. Technical Report ASTRON-SP-062, ASTRON, 2016.

[2] Alessio Sclocco, Joeri van Leeuwen, and Emily Petroff. ARTS Design Pipeline SC3+4 Subsystem. Technical Report ASTRON-RP-1506, ASTRON, 2016.