Initial Report of Activities of the GNSS SDR Metadata Standard Working Group

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BIOGRAPHY

Dr. Sanjeev Gunawardena is a Research Assistant Professor with the Autonomy & Navigation Technology Center at the Air Force Institute of Technology. Previously he was a Senior Research Engineer and Principal Investigator with the Ohio University Avionics Engineering Center, where he led several GNSS software receiver based research and development projects. Dr. Gunawardena earned B.S. in engineering physics, B.S.E.E., M.S.E.E. and Ph.D. in electrical engineering from Ohio University. His research interests include RF design, digital systems design, reconfigurable computing, software-defined radio, and all aspects of GNSS receivers and associated signal processing.

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ABSTRACT

During its January 2014 Meeting in San Diego, the Council of the Institute of Navigation approved the formation of a working group to establish a free and open standard for the exchange of GNSS software radio metadata. The goal of this effort is to promote interoperability between GNSS software defined radio (SDR) data collection systems and SDR processors.

This paper reports early activities of the working group, including efforts to involve a representative cross section of the navigation community, requirements capture of various interests represented, draft technical details to date, and technical issues facing the committee.

BACKGROUND

GNSS software-defined receivers (SDRs) are a rapidly advancing area in GNSS receiver research and design. The last few years have seen tremendous growth in this field. Universities and other research institutions have developed and demonstrated advanced capabilities, particularly with respect to multi-constellation GNSS and GNSS-plus-multi-sensor navigation processing for challenging environments. This rapid pace of innovation is catalyzed by the recent commercial availability of numerous GNSS and multi-sensor data collection equipment, development platforms from several vendors, as well as a number of open-source projects.

Indeed, with today's ongoing deployment of multiple GNSS constellations (not to mention the various regional systems), coupled with the rapid advancements in massively-parallel low-power processors and inexpensive sensors (whose developments are fueled by the current revolution in mobile device technology), it is foreseen that the SDR will likely be a significant commercial GNSS receiver architecture by the end of this decade.

In many non-realtime operational scenarios where GNSS SDRs are used, samples from the receiver front-ends are stored and post-processed. These stored SDR files can also be used in RF playback systems for GNSS receiver testing. Several key front-end parameters (such as RF and IF center frequencies, sample rate, and sample resolution) as well as other information (such as packed-sample format, antenna location and type) are required during post-processing and/or playback. We define this information as GNSS SDR metadata. Currently, for the most part, front-end parameters are entered manually (a process that is cumbersome and error prone to say the least) and no established method exists to exchange this metadata.

During the ION GNSS+ 2013 conference, a group of members discussed the need for a formal standard for the exchange of GNSS SDR metadata. This group identified the following benefits of engaging in this activity at the present time:

- Identifies and brings the international GNSS SDR community together as a working group. This collaboration is critical in order to achieve broad acceptance and usage.
- Standardization will help to avoid technology segmentation issues while promoting the pace of innovation through the use of standard practices and compliant tools.
- The formal standard, if widely adopted, will help ensure compatibility and interoperability of future GNSS SDR systems. Specifically, SDR-based 'plug-and-play' systems that are front-end agnostic can be envisioned. Such systems have the potential for

revolutionizing positioning, navigation, and timing (PNT) systems of the future.

The majority of those who have published on the subject of GNSS SDR during the past two decades are well-known Institute of navigation (ION) members who also happen to be regular meeting attendees. Hence, establishing this standard through ION sponsorship was deemed most appropriate due to logistical reasons and ION's undisputable GNSS SDR subject matter expertise through its membership. This situation is reminiscent of the events that transpired during the early 1990's that culminated in the establishment of ION STD 101: Recommended Test Procedures for GPS Receivers [1].

This initial group of members drafted a Terms of Reference document [2] and submitted to the ION Executive Committee for initial approval. The document outlined the process that would be followed including activities and tentative schedule.

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WORKING GROUP FORMATION AND INITIAL ACTIVITIES

Following ION Council approval and legal review of the invitation materials, invitations to join the working group were sent to a representative international cross section of GNSS SDR subject matter experts from academia, industry and government. More than half of those contacted responded with interest in serving in the working group.

The ION GNSS SDR Metadata Working Group (WG) was formed in April 2014. WG membership represents academia, industry (comprising of GNSS SDR product vendors as well as traditional GNSS equipment manufacturers), non-profit research entities, and government agencies. Currently, representation covers countries in North America, Europe, Asia and Australia. Due to follow-on interest, additional members were added to the group beyond the initial sign-up period. As of this writing, the WG consists of 62 members as listed towards the end of this report (as indicated; only one member from an entity has voting rights). ION also created an online discussion forum for the WG.

Between May and September 2014, the WG reviewed and discussed online two versions of draft proposals. On September 9, the WG had its first in-person meeting coincident with ION GNSS+ 2014. This meeting, which was open to all interested parties, was attended by 30+ individuals – most of whom were WG members. The following items were agreed to through consensus at this meeting:

- Acceptance of second iteration of draft specification with several proposed revisions.
- Adoption of the free and open Extensible Markup Language (XML) as the metadata file format.
- Metadata file naming convention of '*FileName.sdrx*' for an SDR data file named '*FileName.ext*', where '*ext*' may represent any file extension.
- Each SDR file will typically be paired with one metadata file. WG will explore an alternate scheme involving only one metadata file for space-constrained applications.
- A lane-selection metadata file will also be part of the standard. Lane selection applies to spatially-split (or multi stream/multi file) data collection topologies as described later in this paper.
- Establishment of a Documentation Subcommittee.
- Establishment of a Reference Implementation Subcommittee.
- Establishment of a Compliance Verification Subcommittee.
- For the initial version of the standard, scope will be constrained to a set of metadata parameters that allows SDR data files to be fully and unambiguously decoded by a compliant SDR processor.
- The standard will also address a basic set of often-used parameters that describe the data collection campaign (such as antenna location, description of scenario, etc.).
- Additional parameters that are likely to be part of a future revision of the standard (such as models describing the reference oscillator, front-end gain settings, etc.) will be identified in an appendix. This approach promotes the on-schedule release of an initial revision of the standard that addresses the immediate need of the community while recognizing that the standard may evolve to include additional metadata parameters as needed.

The Documentation Subcommittee is responsible for the creation and review of all documentation associated with the WG. All content produced by this group will be distributed to the WG for review and comment prior to release outside the WG.

The WG decided to work on a publicly available reference software library that will be released with the standard. The goal of this effort is to promote early and widespread adoption of the standard by making it easy for vendors and researchers to integrate standard-compliance by integrating the library into their existing software. The scope of this effort was limited to being able to create standard-compliant metadata files from an appropriately-populated data structure, and reading the content of such files back to a data structure.

The primary responsibilities of the Reference Implementation Subcommittee are to reduce to practice the conceptual design developed though consensus by the WG into an appropriate set of XML schema (according to industry best practices) and to develop the compliant software library implementation. The WG was fortunate to receive voluntary participation for this task from individuals representing established commercial GNSS SDR vendors.

A number of WG members volunteered to perform ‘blind testing’ of SDR data files against draft specifications. This involves exchanging SDR data files and associated metadata specifications among parties and verifying that the files can be fully decoded without additional information. WG members participating in this activity will comprise the Compliance Verification Subcommittee.

JUSTIFICATION FOR GNSS METADATA STANDARDIZATION

Figure 1 provides an overview of the metadata exchange process that is currently used in GNSS SDR systems. The top row depicts data collection system (DCS) *A*, producing an SDR file of format *A*, that is processed by SDR processor *A*. This may represent an end-to-end solution provided by a vendor or a system that was initially developed around a specific hardware platform. In any case, assume that the metadata for Format *A* is hard coded into the processor. Consequently, the processor, which may have the inherent capability of processing other types of files (all other parameters being equal except, for example, sampling rate) is unable to do so without a software modification. System *A* may have been used to collect data sets of a rare scenario that the user desires to process with other more-capable SDR processors, or make them available to other research groups that possess such capabilities (SDR *X* and *Y*, for example). This metadata transfer is currently done in an ad-hoc manner that is prone to interpretation errors.

The second row depicts multi-stream DCS *B* that produces files with a more complicated format. SDR processors *X* and *Y* may represent more flexible SDR processors that have been developed by research groups. These SDRs may be able to support multiple file formats, but the data/metadata association is not seamless.

DCS *C* multiplexes other data (such as sensor data) along with multiple GNSS sample streams in the same file. This type of multiplexed data has the potential to become more common with the advent of SDR-related data streaming standards such as VITA-49 [3]. In this case, custom-designed processor *C* represents an SDR that fully supports multi-sensor integration capabilities. Because DCS *C*’s GNSS stream metadata parameters are open, SDR *Y* is also able to support GNSS-only processing using an ad-hoc metadata exchange. The sensor data parameters in Format *C* may or may not be open.

As evident from Figure 1, today’s ad-hoc methods of metadata exchange discourage interoperability and cultivates potential for technology segmentation.

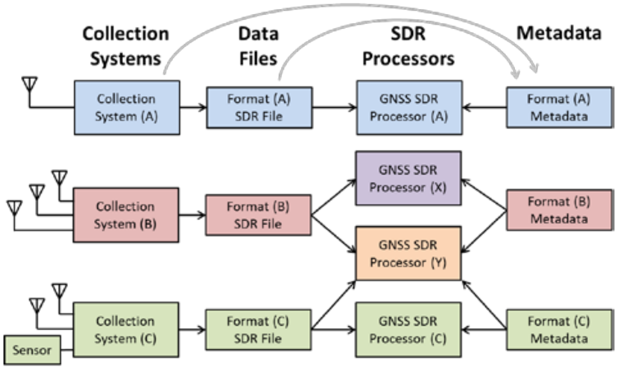

Figure 1 – Ad-hoc Metadata Exchange

Figure 2 shows the same GNSS SDR systems of Figure 1 that have adopted the metadata standard. As shown, each DCS associates a compliant metadata file with the SDR files that are produced. The metadata file is read-in by the compliant SDR processor to correctly interpret and decode the SDR file.

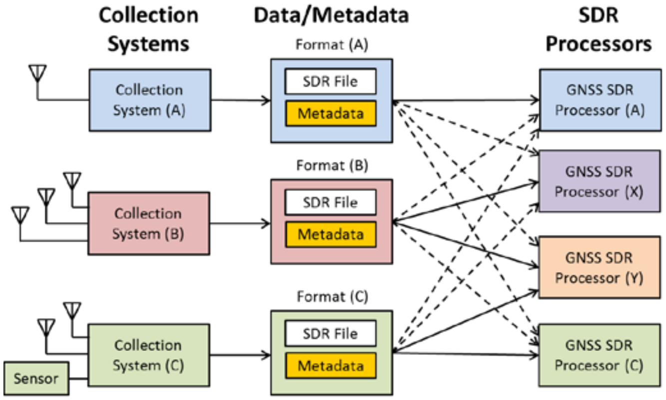

Figure 2 – Standardized Metadata Exchange

As evident from the figure, standard adoption benefits DCS developers because their SDR files become useful to a much wider audience. Similarly, an SDR processor’s utility is extended when it is capable of supporting numerous file formats from multiple sources. Thus, metadata standardization promotes interoperability of GNSS SDR systems and greatly simplifies the exchange of GNSS SDR data files between research groups.

GNSS SDR metadata standardization also benefits other use cases beyond the collect-then-offline-process model described thus far. For example, consider the use of the metadata specification to synthesize compliant SDR files for use in RF playback systems. Additionally, libraries of compliant SDR file sets containing various real-world scenarios could be used interchangeably in compliant RF playback simulators for repeatable and consistent testing of GNSS receivers.

SDR DATA COLLECTION TOPOLOGIES

A stipulation that the ION Executive Committee brought the initial committee's attention to during the approval of this standardization activity was that the outcome shall not create an unfair advantage or disadvantage to any entity. Specifically, the standard shall not require any existing system to have to be modified (or their data format changed) in order to achieve compliance. This *'do no harm'* stipulation means that the standard must be designed such that it supports the majority of all SDR file formats that currently exist, and may exist in the future. This also means that the WG must *'get it right the first time'* since major revisions to the standard would be undesirable and adverse to the goal of widespread adoption. Hence, prior to defining metadata parameters, the entire space of possible GNSS SDR data collection topologies must be understood. Figure 3 illustrates these topologies.

Figure 3.a illustrates the simplest data collection topology that can exist. This is when a single swath of RF spectrum (referenced henceforth as a 'band') is down-converted and sampled to produce a single data stream. The stream, which may be IF sampled (real data) or baseband sampled (complex data) is written to disk as a single file.

Figure 3.b is similar to Figure 3.a, except that the data stream contains information from more than one RF band. An example of this topology is a direct RF sampling front-end architecture that intentionally aliases multiple bands to fall next to each other at baseband. In this case, some bands may be spectrally inverted as a result of the digital down-conversion process.

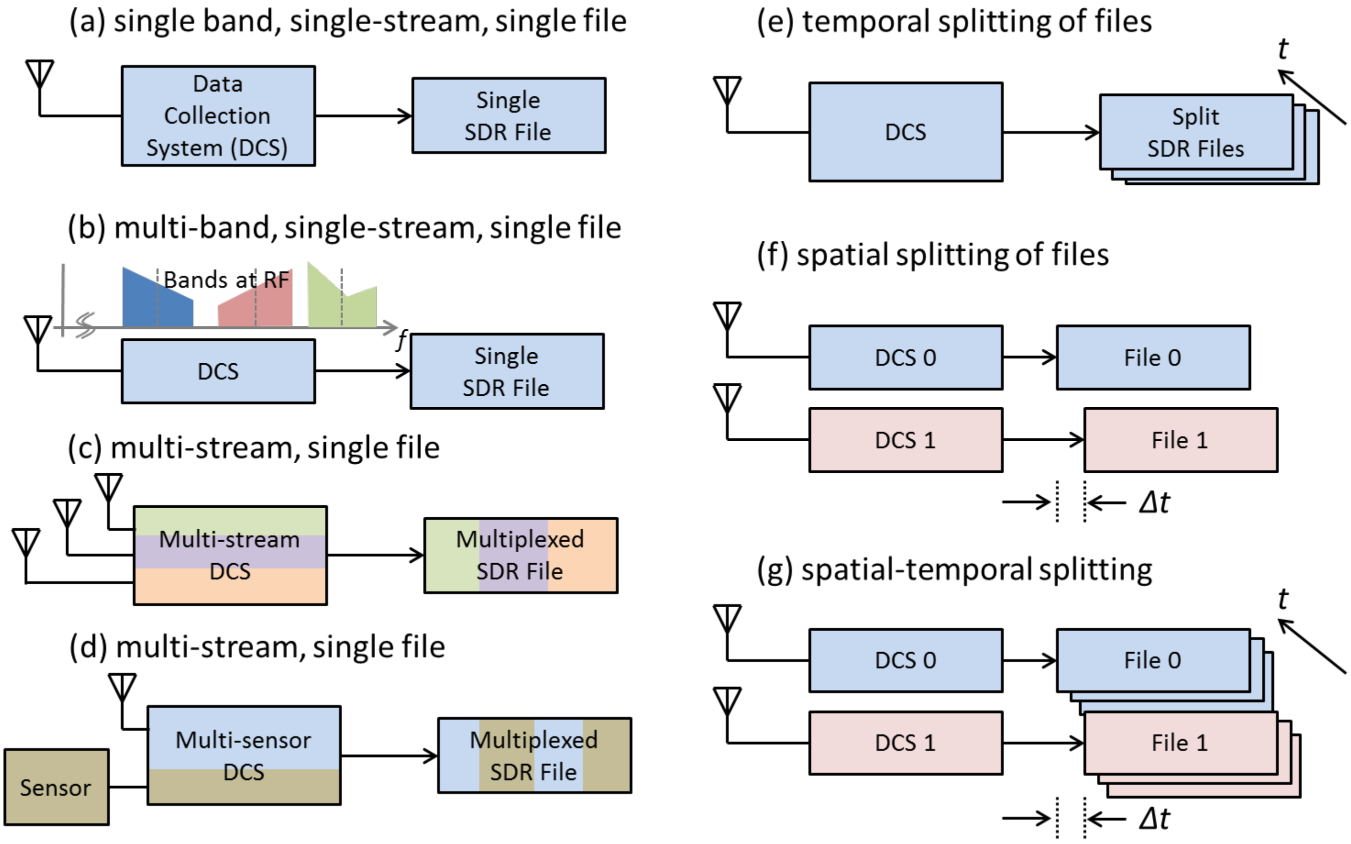

Figure 3 – GNSS SDR Data Collection Topologies

A DCS may produce multiple data streams. Each stream may contain information from one of many antenna elements (as shown in Figure 3.c, where each stream may also encompass multiple bands as in Figure 3.b). Alternatively, a stream may be sampling one of several bands received by a single antenna. Combinations of these are also possible.

Each stream may be also be sampled at different rates and bit depths. For example, consider a civilian GPS L1, L2, L5 system. In this case, the L1 and L2 streams may be sampled at rate f_0 and the L5 stream at $10 \cdot f_0$ (since the L5 signal's null-to-null bandwidth is ten times wider than L1 C/A and L2C), where f_0 represents the base sample rate. Figure 3.c illustrates how these multiple streams are multiplexed into a single lane of packed binary data and written to a single file.

Similar to Figure 3.c, Figure 3.d illustrates a GNSS data stream multiplexed with other data that is written to a single file. This non-GNSS SDR data may be from additional sensors (as shown), and may be written in a proprietary format that may or may not be known.

The specification of metadata parameters for non-GNSS data is outside the scope of this standardization effort. However, the standard must support adequate information to skip over such non-GNSS data bytes and correctly decode all GNSS samples. Since the XML format is extensible by definition, this does not preclude the standard's metadata schema from being extended by the vendor to also cover the non-GNSS SDR data. These non-compliant parameters will simply be ignored by SDR processors that cannot interpret them.

It is important to note that although we use the term 'GNSS SDR data' in this paper to generally refer to the type of sampled data for which metadata parameters will be defined in the standard, the samples need not correspond to GNSS frequency bands. For example, frequency bands containing signals of opportunity are supported as long as they can be defined by the standard's appropriate metadata parameters.

Due to the typically high data rate of GNSS SDRs, some DCSs write data as temporally split files, as illustrated in Figure 3.e. This allows files to be managed more efficiently compared to a single large file. The metadata for each file must associate the previous and next files in order to correctly reconstruct the sequence. Note that the DCS block shown in Figure 3.e could represent any of those described in topologies (a) thru (d) in Figure 3.

Figure 3.f illustrates spatial splitting of files. Here, the binary data lanes from two or more DCSs are written to separate files. These files may be written by different computer systems. In this case, a non-zero inter-system timing offset, Δt, may exist and must be supported in the standard. Since Δt may or may not be known at time of collection, it represents an example metadata parameter that may be back-annotated into the metadata file after an initial pass of SDR data processing.

Multi-lane DCSs that write each lane to a separate file may also implement temporal file splitting as was done in topology (e). This type of topology is referred to as 'spatial-temporal splitting' and is illustrated in Figure 3.g.

Since multi-stream-multi-file data collection topologies (i.e. (*f*) and (*g*) in Figure 3) produce multiple data files applicable to a given time interval, the SDR processor must be 'introduced' to the full or partial set of lanes associated with the topology. This will be handled by lane selection metadata parameters in the standard.

NOTIONAL METADATA PARAMETERS

Figure 4 illustrates the proposed methodology for associating metadata parameters with GNSS SDR data files created by a DSC. The metadata parameter set, their formal names and definitions are currently under development by the WG. Additional details will be available in the initial draft standard document scheduled to be released in October 2014.

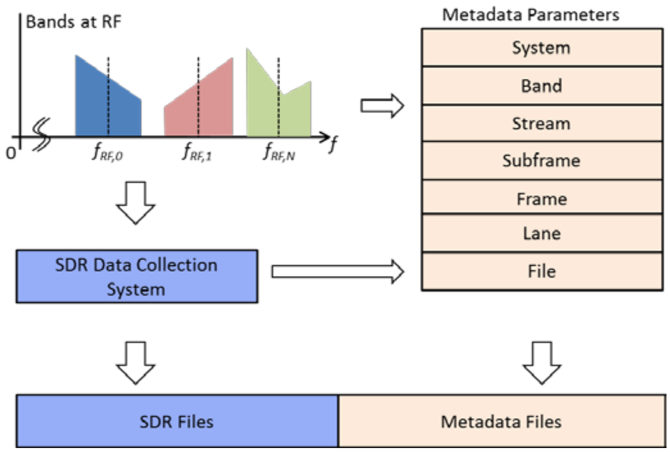

Figure 4 – Association between SDR Data Files and Metadata Parameters

SUMMARY, DRAFT STANDARD AVAILABILITY AND INVITATION FOR FEEDBACK

This paper reports on the formation and initial activities of the ION GNSS SDR Metadata Standardization Working Group. The goal of this effort is to promote interoperability between GNSS SDR data collection systems and processors. Efforts to involve a representative cross section of the navigation community, requirements capture of various interests represented, draft technical details to date, and technical issues facing the committee were described.

The first draft of the standard is planned for release in October 2014. ION members and the general public are encouraged to provide their comments using the online feedback submission portal that will be available through the ION website: www.ion.org.

Working Group participation is open to any individual with demonstrable expertise in the subject matter and desires to actively contribute to the group's efforts. Those wishing to serve are encouraged to contact the Working Group co-chairs, preferably through nomination from a working group member.

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ZHU, Zhen	*East Carolina University*

* indicates non-voting member

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