Ranging Service

Bluetooth® Service Specification

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- **Prepared By:** Direction Finding Working Group

Abstract:

The Ranging Service (RAS) is specified to allow the distance-measurement application to read ranging data from the remote device and to configure the ranging parameters. By enabling high-accuracy distance measurement between Bluetooth devices, new user scenarios are possible.

Version History

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Contents

1 Introduction

This document specifies the Ranging Service (RAS), a Generic Attribute Profile (GATT) service intended for providing Ranging Data to a client. Ranging Data is the Channel Sounding (CS) Procedure results that are generated by a Core Controller (a Controller as defined in the Core Specification [1]) and sent to the Host via Host Controller Interface (HCI) Low Energy (LE) CS Subevent Result and Subevent Result Continue events (see Table 3.1 in Volume 4, Part E, Section 3 of [1]). Ranging Data can be used by the client to perform a distance estimation.

The Core Controller on the GATT Server (i.e., RAS Server) side shall have either the Initiator role, the Reflector role, or both roles defined (see Volume 1, Part A, Section 3.3.2.5.3 of [1]). The Initiator and Reflector roles are independent from the GAP Central and Peripheral roles, which means that a Core Controller that implements the Central or Peripheral role can support either the Initiator or the Reflector role.

The Initiator and Reflector roles run the CS Procedure in the Core Controller (see Volume 1, Part A, Section 9 in [1]), where a CS Procedure consists of CS Events, Subevents, and Steps. These define a set of time and frequency slots in which two devices agree to communicate and exchange a combination of radio frequency (RF) signals. The purpose of that exchange is to provide the phase-based ranging (PBR) and round-trip time (RTT) data between the Initiator and Reflector (see Volume 6, Part H of [1]).

A CS procedure is divided into one or more CS Events. A CS Event consists of one or more CS Subevents and a CS Subevent consists of two or more CS Steps. An LE CS Subevent Result event and zero or more LE CS Subevent Result Continue events are generated per CS Subevent. Four CS Step types, known as mode-0 through mode-3, are defined. Each mode is used for a specific purpose (see Volume 1, Part A, Section 9 of [1]).

Figure 1.1 shows the relationship between the CS Procedures, Events, Subevents, and Steps.

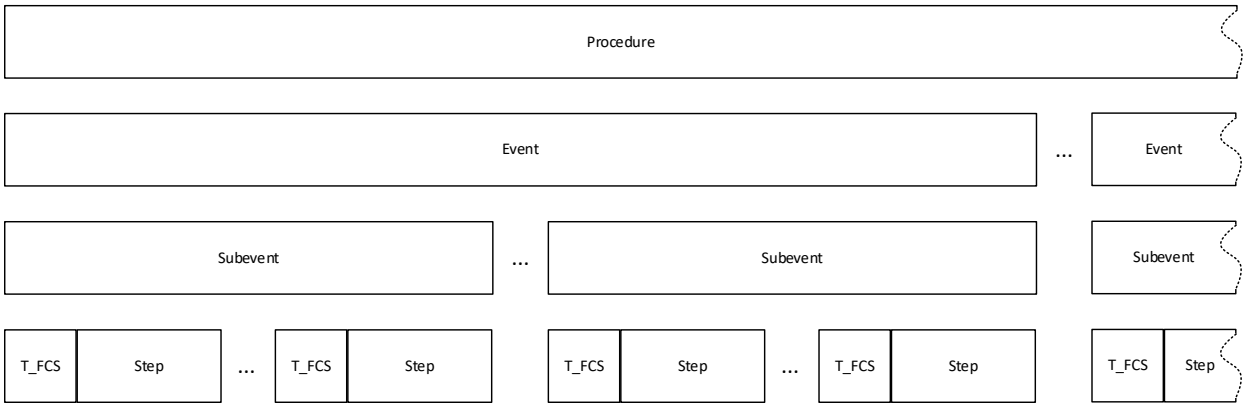

Figure 1.1: CS Procedure, Event, Subevent, and Step hierarchy

Figure 1.2 shows an overview of the end-to-end CS setup and CS ranging phases, including the RAS result exchanges.

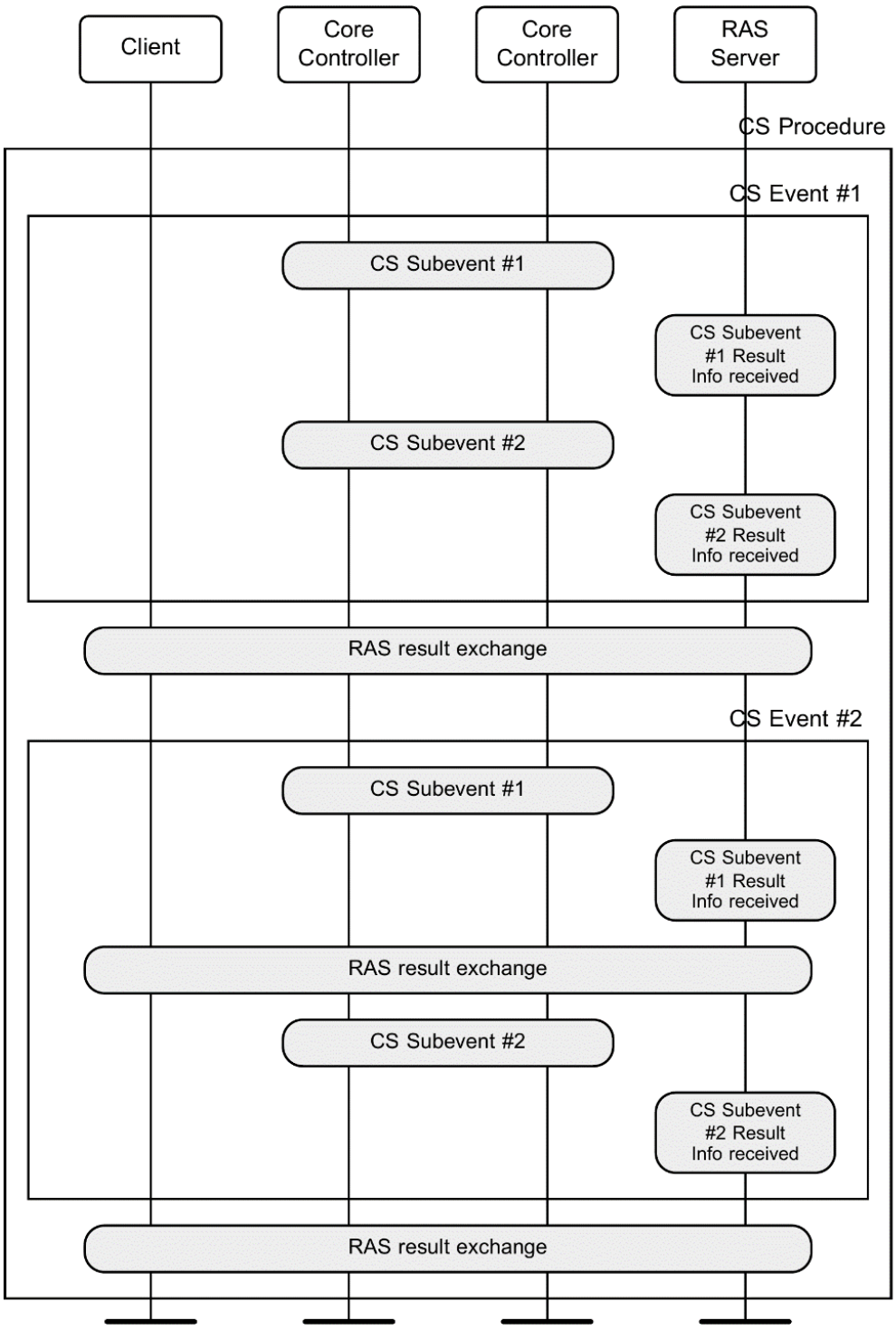

Figure 1.2: Full end-to-end CS flow diagram, including RAS result exchange

The Host on the RAS Server side will receive the Ranging Data for each CS Subevent from the local Core Controller either while the CS Procedure is running or after it is finished. The RAS Server sends the Ranging Data to the client per a CS Procedure or per a CS Subevent. The total size of the Ranging Data for one procedure can reach up to approximately 5 KB. One of the main objectives of RAS is to specify an optimized method for forwarding the Ranging Data from the RAS Server to the client in a timely manner.

1.1 Language

1.1.1 Language conventions

In the development of a specification, the Bluetooth SIG has established the following conventions for use of the terms *"shall"*, *"shall not"*, *"should"*, *"should not"*, *"may"*, *"must"*, and *"can"*. In this Bluetooth specification, the terms in Table 1.1 have the specific meanings given in that table, irrespective of other meanings that exist.

Term	Definition
shall	—used to express what is required by the specification and is to be implemented exactly as written without deviation
shall not	—used to express what is forbidden by the specification
should	—used to express what is recommended by the specification without forbidding anything
should not	—used to indicate that something is discouraged but not forbidden by the specification
may	—used to indicate something that is permissible within the limits of the specification
must	—used to indicate either: 1. an indisputable statement of fact that is always true regardless of the circumstances 2. an implication or natural consequence if a separately-stated requirement is followed
can	—used to express a statement of possibility or capability

Table 1.1: Language conventions terms and definitions

1.1.1.1 Implementation alternatives

When specification content indicates that there are multiple alternatives to satisfy specification requirements, if one alternative is explained or illustrated in an example it is not intended to limit other alternatives that the specification requirements permit.

1.1.1.2 Discrepancies

It is the goal of Bluetooth SIG that specifications are clear, unambiguous, and do not contain discrepancies. However, members can report any perceived discrepancy by filing an erratum and can request a test case waiver as appropriate.

1.1.2 Reserved for Future Use

Where a field in a packet, Protocol Data Unit (PDU), or other data structure is described as "Reserved for Future Use" (irrespective of whether in uppercase or lowercase), the device creating the structure shall set its value to zero unless otherwise specified. Any device receiving or interpreting the structure shall ignore that field; in particular, it shall not reject the structure because of the value of the field.

Where a field, parameter, or other variable object can take a range of values, and some values are described as "Reserved for Future Use," a device sending the object shall not set the object to those values. A device receiving an object with such a value should reject it, and any data structure containing it, as being erroneous; however, this does not apply in a context where the object is described as being ignored or it is specified to ignore unrecognized values.

When a field value is a bit field, unassigned bits can be marked as Reserved for Future Use and shall be set to 0. Implementations that receive a message that contains a Reserved for Future Use bit that is set to 1 shall process the message as if that bit was set to 0, except where specified otherwise.

The acronym RFU is equivalent to Reserved for Future Use.

1.1.3 Prohibited

When a field value is an enumeration, unassigned values can be marked as “Prohibited.” These values shall never be used by an implementation, and any message received that includes a Prohibited value shall be ignored and shall not be processed and shall not be responded to.

Where a field, parameter, or other variable object can take a range of values, and some values are described as “Prohibited,” devices shall not set the object to any of those Prohibited values. A device receiving an object with such a value should reject it, and any data structure containing it, as being erroneous.

“Prohibited” is never abbreviated.

1.2 Table requirements

Requirements in this specification are defined as "Mandatory" (M), "Optional" (O), "Excluded" (X), “Not Applicable” (N/A), or "Conditional" (C.n). Conditional statements (C.n) are listed directly below the table in which they appear.

1.3 Conformance

Each capability of this specification shall be supported in the specified manner. This specification may provide options for design flexibility, because, for example, some products do not implement every portion of the specification. For each implementation option that is supported, it shall be supported as specified.

1.4 Byte transmission order

All characteristics used with this service shall be transmitted with the least significant octet (LSO) first (i.e., little endian). Where the format is described in tables in this document, the LSO is the first octet in the topmost field of the table; the most significant octet (MSO) is the last octet in the bottommost field of the table. Where characteristics are defined in the GATT Specification Supplement (GSS), see GSS Section 2.2 [2] for more information on octet ordering.

2 Service

2.1 Service dependencies

RAS does not depend on any other service.

2.2 Bluetooth Core Specification release compatibility

This service is compatible with the Bluetooth Core Specification, Version 6.0 or later [1].

2.3 Transport dependencies

RAS only works over LE transport.

2.4 Attribute Protocol Application error code

RAS references common Protocol and Service error codes (listed in Table 2.1) that are defined in Part B, Section 1 of the Bluetooth Core Specification Supplement (CSS) [3].

Name	Error Code	Description
Client Characteristic Configuration Descriptor Improperly Configured	0xFD	Used when a Client Characteristic Configuration (CCC) descriptor is not configured according to the requirements of the profile or service.
Write Request Rejected	0xFC	Used when a requested write operation cannot be fulfilled for reasons other than permissions.

Table 2.1: Attribute Protocol (ATT) Application error code

2.5 GATT sub-procedure requirements

Requirements in this section represent a minimum set of requirements for a GATT Server. Other GATT sub-procedures may be used if supported by both the client and the server.

Table 2.2 summarizes additional GATT sub-procedure requirements beyond those required by all GATT Servers.

GATT Sub-Procedure	Requirements
Write Without Response	M
Exchange MTU	M
Characteristic Value Notification	M
Characteristic Value Indication	M
Read Characteristic Descriptors	M

GATT Sub-Procedure	Requirements
Write Characteristic Descriptors	M
Read Characteristic Value	M

Table 2.2: GATT sub-procedure requirements

2.6 Declaration

A single RAS instance shall be instantiated as a «Primary Service». The service's Universally Unique Identifier (UUID) shall be set to «Ranging Service» as specified in [4].

2.7 Behavior

RAS enables the client to read Ranging Data from a RAS Server. RAS is implemented on a device that can generate Ranging Data by using the Channel Sounding (CS) feature of the local Core Controller. RAS distinguishes between two modes of Ranging Data exchange, each represented by a service characteristic:

- **Real-time Ranging Data**: Ranging Data that is received from the local Core Controller and communicated immediately by the RAS Server while connected to the client
- **On-demand Ranging Data**: Ranging Data that is received from the local Core Controller and stored on the RAS Server for On-demand retrieval by the client

The client can enable one of these modes by subscribing to either notifications or indications of either the Real-time Ranging Data characteristic or the On-demand Ranging Data characteristic by writing to the CCC descriptor associated with these characteristics.

The RAS Server shall operate in either Real-time or On-demand mode, but not both simultaneously. A client can switch from one mode to the other by first disabling the active mode and then enabling the other mode. If the client enables more than one mode, then the RAS Server shall reject the Write Characteristic Descriptors request and return a Client Characteristic Configuration Descriptor Improperly Configured error code (see Table 2.1).

If the RAS Server does not support notifications for a characteristic and the client enables notifications for that characteristic, then the RAS Server shall reject the Write Characteristic Descriptors request and return a Write Request Rejected (see Table 2.1).

A RAS Server shall transfer Ranging Data in chronological order, with the oldest being sent first. This requirement applies to both an On-demand Ranging Data exchange that is transferred in a RAS Control Point procedure (see Section 3.4) and a Real-time Ranging Data exchange.

If the Asynchronous Connection-oriented logical transport (ACL) connection with the client is lost or terminated during the Real-time or On-demand Ranging Data exchange, then the RAS Server shall flush any pending Ranging Data segments.

2.7.1 RAS Real-time behavior

As shown in Figure 2.1, the RAS Server that is operating in the Real-time Ranging Data mode may begin transferring the Ranging Data in a real-time manner as soon as the CS Subevent result is received from the local Core Controller and the Ranging Data meets the segmentation requirements in Section 3.2.2. As

a result, the Real-time Ranging Data notifications or indications may start while the CS Procedure is still ongoing.

The Ranging Data Ready indication is used only in the On-demand Ranging Data mode (see Section 3.4). The RAS Server shall not indicate the Ranging Data Ready indication in Real-time Ranging Data mode.

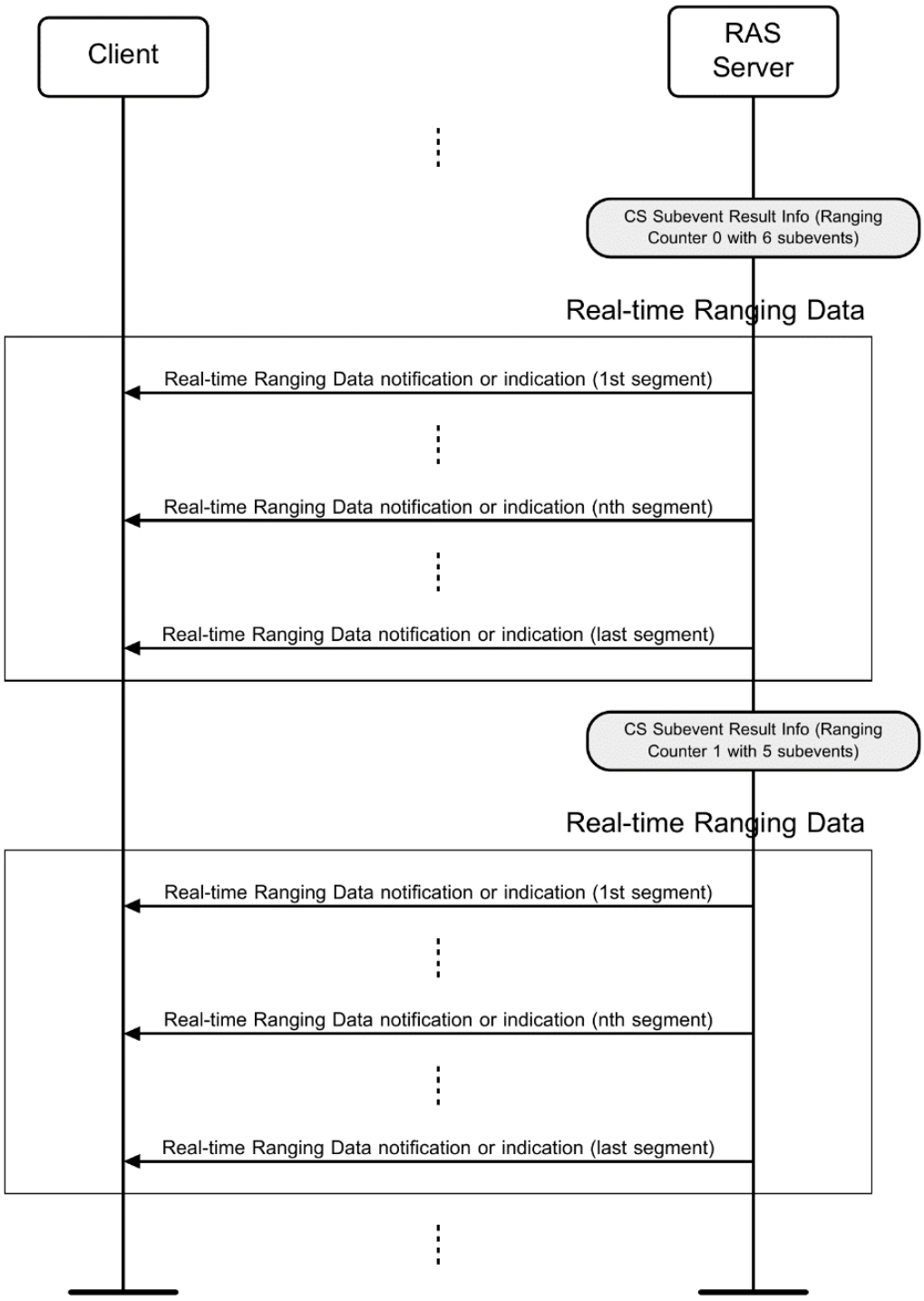

Figure 2.1: ***Message sequence chart for Real-time Ranging Data***

2.7.2 RAS On-demand behavior

As shown in Figure 2.2, when the client enables Ranging Data Ready indications or notifications (see Section 3.4), and new Ranging Data is available, the RAS Server shall indicate the Ranging Data Ready indication (see Section 3.4). In response, the client writes the Get_Ranging_Data command to the RAS Control Point, and the RAS Server shall indicate or notify the Ranging Data using the On-demand Ranging Data characteristic. When all Ranging Data for a given request has been indicated or notified by the RAS Server, the RAS Server shall indicate the RAS Control Point with a Complete_Ranging_Data Response Op Code and the Parameter set to the Ranging Counter reported. After the client receives the last Ranging Data segment, the client sends the ACK_Ranging_Data command.

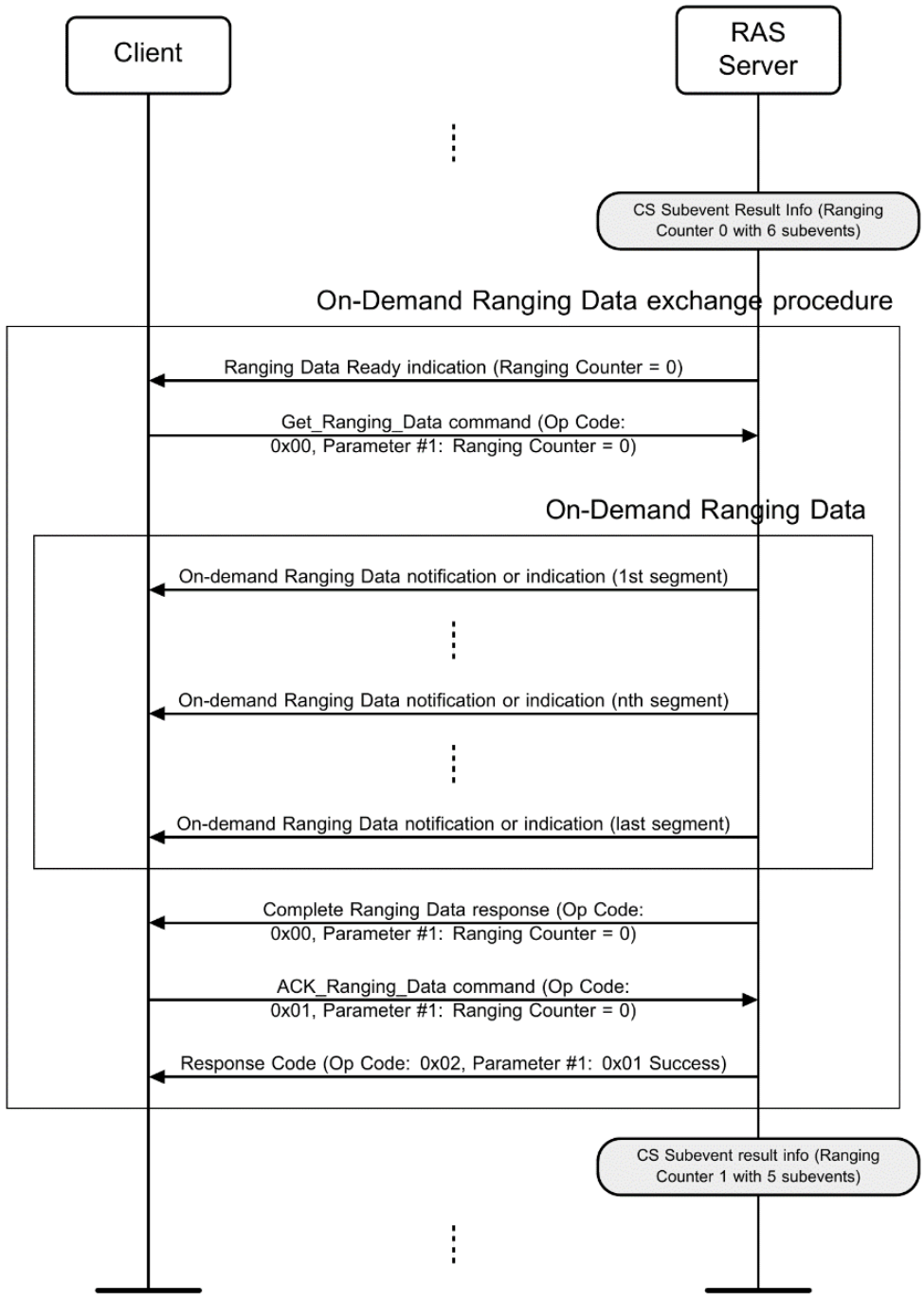

Figure 2.2: Message sequence chart for On-demand Ranging Data using RAS Control Point

2.7.2.1 Ranging Data retention requirements

The RAS Server shall store the Ranging Data for at least one CS Procedure, where each CS Procedure includes up to 32 CS Subevent Results and 256 CS Step Data (see Volume 6, Part B, Section 4.5.18.1 in [1]). The RAS Server may queue Ranging Data of more than one CS Procedure (i.e., the entire CS Procedure results).

If the RAS Server runs out of memory after the first CS Subevent Result for the new CS Procedure is received, then the entire oldest Ranging Data shall be deleted.

2.7.2.2 Ranging Data Overwritten and Segment loss behavior

When the RAS Server overwrites the unread Ranging Data with the new Ranging Data, it shall inform the client with a Ranging Data Overwritten indication or notification, as shown in Figure 2.3 (see Section 3.5).

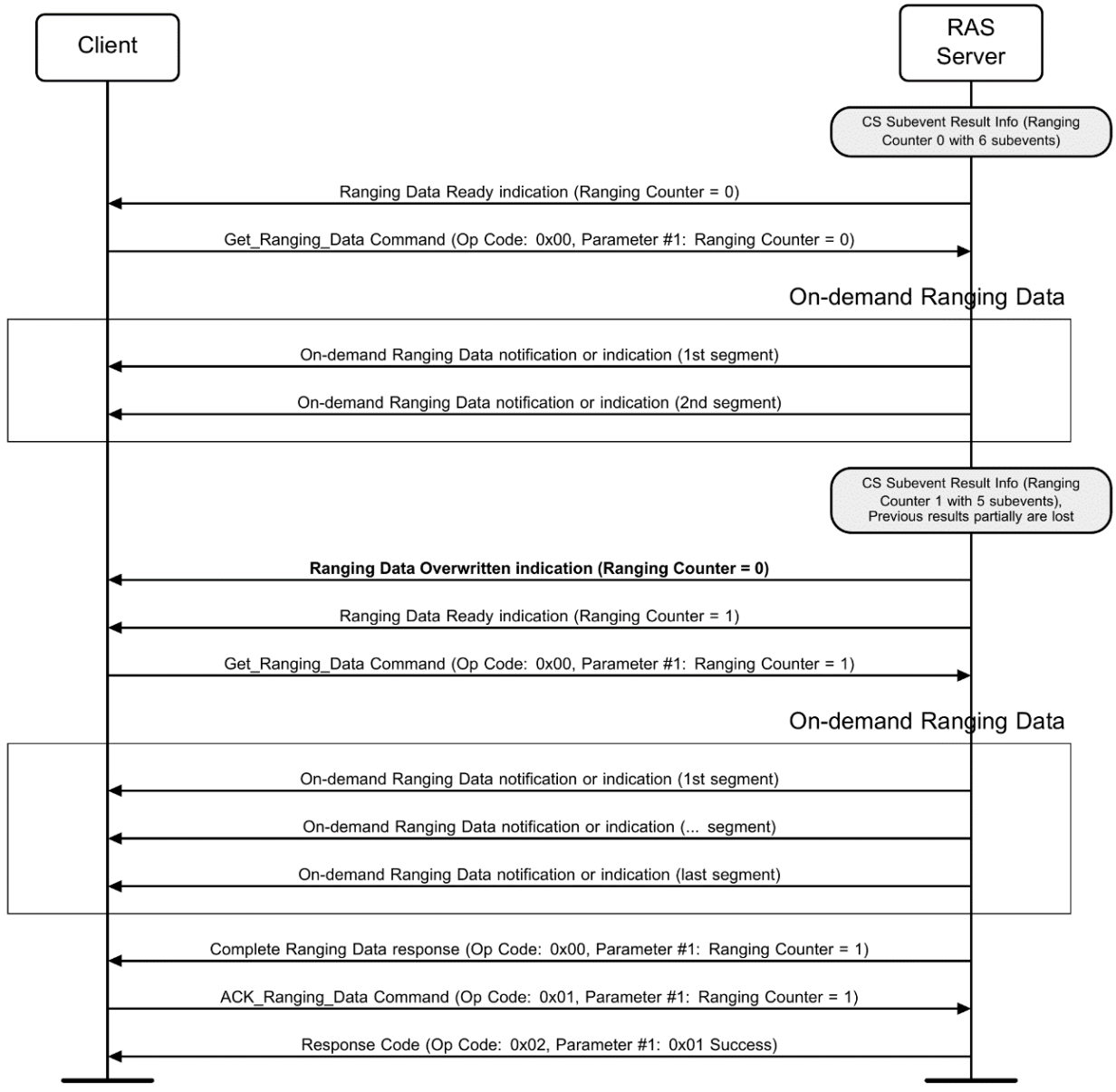

Figure 2.3: Ranging Data overwritten and Ranging Data Overwritten indication sent by RAS Server

Figure 2.4 shows an example of an On-demand Ranging Data indication or notification segment loss. In this example, the indication or notification with Rolling Segment Counter = 10 is lost and the client sends a Retrieve_Lost_Ranging_Segment command with the Start segment counter = 10 and the End segment counter = 10 to retrieve the lost segment. The RAS Server sends the requested On-demand Ranging Data indication or notification with a specific segment counter and sends a Complete Lost Ranging Segment Response to indicate the end of the Retrieve Lost Ranging Data Segments procedure. Finally, the client acknowledges the reception of complete Ranging Data by writing the ACK_Ranging_Data Op Code to the RAS Control Point.

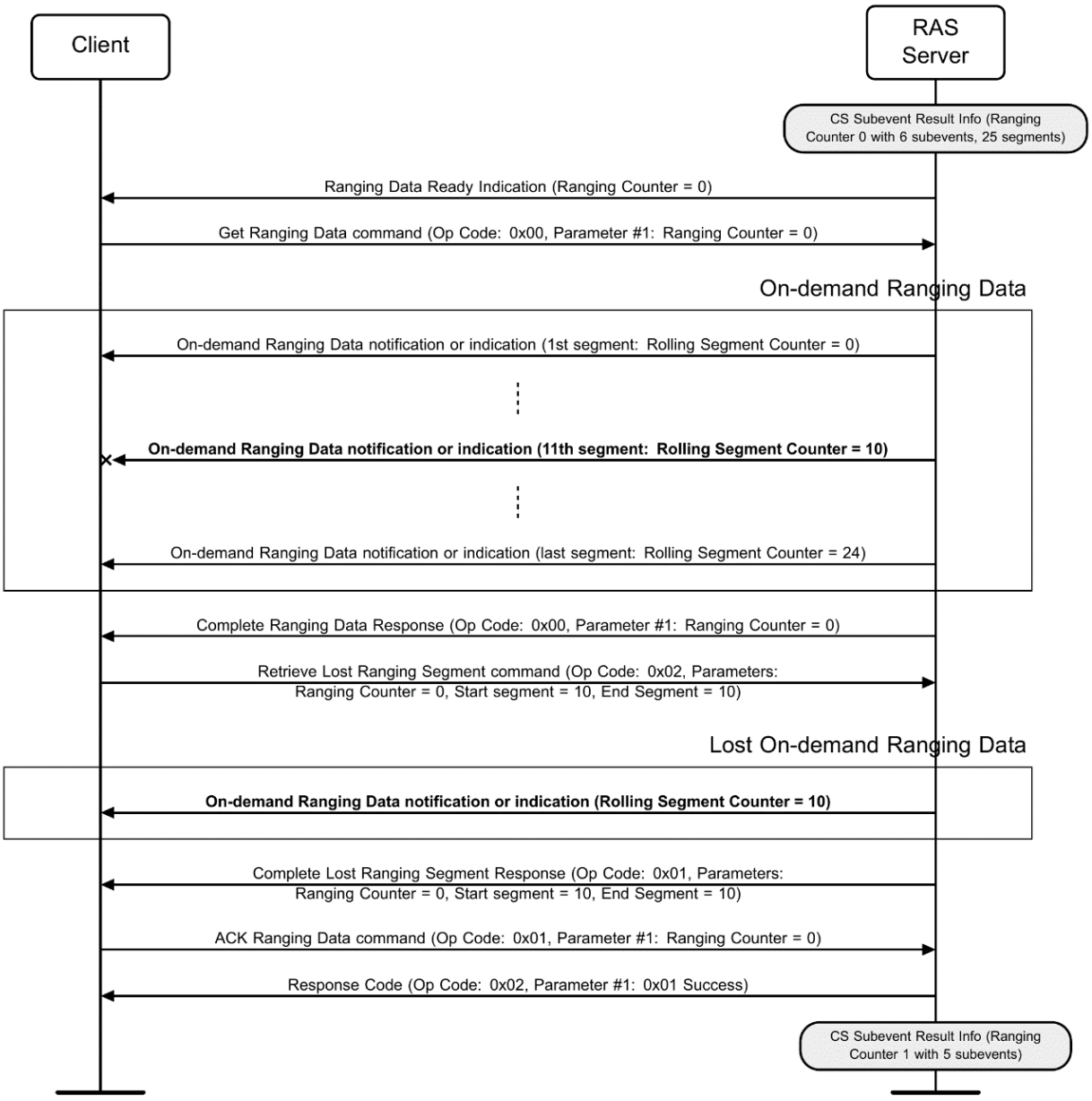

Figure 2.4: On-demand Ranging Data Segment failure and retrieval of lost segment procedure for On-demand Ranging Data using RAS Control Point

3 Service characteristics

RAS shall expose the characteristics listed in Table 3.1. These characteristics may be notified, indicated, read, or written (where the characteristic properties allow) to receive the Ranging Data. Where a characteristic can be indicated or notified, a CCC descriptor must be included in that characteristic.

There shall be only one instance of RAS characteristics within the service definition. The RAS Server shall maintain independent characteristic values for each client.

Characteristic Name	Requirement	Mandatory Properties	Optional Properties	Security Permissions
RAS Features	M	Read	None	Encryption required
Real-time Ranging Data	O	Indicate, Notify	None	Encryption required
On-demand Ranging Data	M	Indicate, Notify	None	Encryption required
RAS Control Point	M	Write Without Response, Indicate	None	Encryption required
Ranging Data Ready	M	Indicate	Notify, Read	Encryption required
Ranging Data Overwritten	M	Indicate	Notify, Read	Encryption required

Table 3.1: Characteristics for use with RAS

3.1 RAS Features

The RAS Features characteristic is used to describe the supported features of the RAS Server.

The structure of this characteristic is stated in Table 3.2.

Field	Data Type	Size (in octets)	Description
RAS Features	Boolean [32]	4	See Section 3.1.1.

Table 3.2: Structure of the RAS Features characteristic

3.1.1 RAS Features format

The RAS Features characteristic bit formats are listed in Table 3.3.

Bit	Definition
0	Real-time Ranging Data
1	Retrieve Lost Ranging Data Segments
2	Abort Operation

Bit	Definition
3	Filter Ranging Data
4-31	RFU

Table 3.3: RAS Features field

3.1.2 RAS Features behavior

The RAS Server shall support the RAS Features characteristic that describes the supported features of the RAS Server. When read, the RAS Features characteristic returns a value that is used by the client to determine the supported features of the RAS Server.

3.2 Real-time Ranging Data and On-demand Ranging Data

3.2.1 Ranging Data format

The Real-time Ranging Data and On-demand Ranging Data characteristics shall use the format defined in Table 3.4.

Field	Requirement	Data Type	Size (in octets)	Description
Segmentation Header	M	uint8	1	See Table 3.5.
Ranging Data Segment	M	struct	variable	A segment of a Ranging Data Body structure as defined in Table 3.6. Segmentation is defined in Section 3.2.1.3.

Table 3.4: Real-time Ranging Data characteristic format

3.2.1.1 Segmentation Header

A 1-byte segmentation scheme is used to transfer Ranging Data payloads that do not fit in a single Maximum Transmission Unit (MTU). Table 3.5 defines the values of the Segmentation Header field. The RAS Server shall use these values to provide information to the client on the segments to concatenate to get a complete Ranging Data Body structure.

Bit Number	Definition
0	First Segment: The characteristic contains the first segment of the Ranging Data that should be concatenated by the client. 0 = False 1 = True
1	Last Segment: The characteristic contains the last segment of the Ranging Data that should be concatenated by the client. 0 = False 1 = True

Bit Number	Definition
2-7	Segment Index: 0 to 63 The Segment Index contains the value of the Rolling Segment Counter (see Section 3.2.1.3).

Table 3.5: Segmentation Header field structure

3.2.1.2 Ranging Data Body

The Ranging Data Body is the data object that contains all the headers and Ranging Data of a CS Procedure. The structure of the Ranging Data Body is shown in Table 3.6.

Field	Description
Ranging Header	See Table 3.7.
Subevent 0 Header and Data	See Table 3.8.
…	
Subevent n Header and Data	See Table 3.8.

Table 3.6: Ranging Data Body structure

The structure of the Ranging Header is shown in Table 3.7.

Field	Size (bits)	Description
Ranging Counter	12	Ranging Counter is lower 12-bits of CS Procedure_Counter (see Volume 4, Part E, Section 7.7.65.44 in [1]) provided by the Core Controller.
Configuration ID	4	CS configuration identifier. Range: 0 to 3
Selected TX power	8	Transmit power level used for the CS Procedure. Range: -127 to 20 Units: decibels referenced to 1 milliwatt (dBm)
Antenna Paths Mask	8	Antenna paths that are reported: Bit0: 1 if Antenna Path_1 included; 0 if not. Bit1: 1 if Antenna Path_2 included; 0 if not. Bit2: 1 if Antenna Path_3 included; 0 if not. Bit3: 1 if Antenna Path_4 included; 0 if not. Bits 4-7: RFU

Table 3.7: Ranging Header structure

Because there may be multiple Ranging Data stored in RAS Server, a Ranging Counter is used to enable individual identification of multiple Ranging Data within a single RAS Server device.

The structure of Subevent Header and Data fields is shown in Table 3.8.

	Field	Size (bits)	Description
Subevent Header	Start ACL Connection Event	16	Starting ACL connection event count for the results reported in the event.
	Frequency Compensation	16	Frequency compensation value in units of 0.01 parts per million (ppm) (15-bit signed integer).
	Ranging Done Status	4	0x0: All results complete for the CS Procedure 0x1: Partial results with more to follow for the CS Procedure 0xF: All subsequent CS Procedures aborted All other values: RFU
	Subevent Done Status	4	0x0: All results complete for the CS Subevent 0xF: Current CS Subevent aborted All other values: RFU
	Ranging Abort Reason	4	Indicates the abort reason when the Procedure_Done Status received from the Core Controller (see Volume 4, Part 4, Section 7.7.65.44 in [1]) is set to 0xF; otherwise, the value is set to zero. 0x0: Report with no abort 0x1: Abort because of local Host or remote request 0x2: Abort because filtered channel map has less than 15 channels 0x3: Abort because the channel map update instant has passed 0xF: Abort because of unspecified reasons All other values: RFU
	Subevent Abort Reason	4	Indicates the abort reason when the Subevent_Done_Status received from the Core Controller (see Volume 4, Part 4, Section 7.7.65.44 in [1]) is set to 0xF; otherwise, the default value is set to zero. 0x0: Report with no abort 0x1: Abort because of local Host or remote request 0x2: Abort because no CS_SYNC (mode 0) was received 0x3: Abort because of scheduling conflicts or limited resources 0xF: Abort because of unspecified reasons All other values: RFU

	Field	Size (bits)	Description
	Reference Power Level	8	Reference power level. Range: -127 to 20 Units: dBm
	Number Of Steps Reported	8	Number of steps in the CS Subevent for which results are reported. If the Subevent is aborted, then the Number Of Steps Reported can be set to zero.
Subevent Data	Step_Mode [i]	Number Of Steps Reported times 8	Bit 0-1: Mode type; range: 0x00-0x03 Bit 2-6: RFU Bit 7: 1 means Aborted, 0 means Success If the Step is aborted and bit 7 is set to 1, then bits 0-6 do not contain any valid data and the length of Step_Data [i] is 0.
	Step_Data [i]	Variable	Mode- and role-specific information being reported.

Table 3.8: Subevent Header and Data structure

Ranging Data stored by a RAS Server may contain zero or more CS Subevent Data elements, up to a maximum of 32 elements. The CS Subevent Data can have 1-3 Mode 0 Step results and multiple non-Mode 0 Step results, where the maximum number of CS Steps per CS Subevent is 160 and the maximum number of CS Steps per CS Procedure is 256 (see Volume 6, Part B, Section 4.5.18.1 in [1]).

The CS Step Data used in the Subevent Data structure is defined in Volume 4, Part 4, Section 7.7.65.44 in [1].

The reported Ranging Data shall only contain the data required by the filter if the client configured a Ranging Data Filter via the RAS Control Point filter procedure (see Section 3.3.2.4).

3.2.2 Ranging Data segmentation

If the total size of the received Ranging Data is greater than (ATT_MTU-4), then multiple segments shall be sent to transfer the entire Ranging Data Body (the data to be transported).

Note that the number of segments that need to be sent to convey the data to be transported is represented by N, which shall be calculated by dividing the size of the data to be transported by (ATT_MTU-4), rounded up to the nearest integer.

When the Real-time Ranging Data characteristic or the On-demand Ranging Data characteristic are configured for indications or notifications via the CCC descriptor, these characteristics shall be indicated or notified per segment as described in the following sequence:

1. If N=1, then the First Segment bit and the Last Segment bit of the Segmentation Header field shall both be set to a value of 1.
2. If N>1, then the First Segment bit of the Segmentation Header field shall be set to a value of 1 and the Last Segment bit shall be set to a value of 0.
3. The Rolling Segment Counter shall be set to the Rolling Segment Counter value maintained by the RAS Server.

4. Up to (ATT_MTU-4) octets of the data to be transported shall be used to fill the Real-time Ranging Data or On-demand Ranging Data characteristic message.
5. The Real-time Ranging Data characteristic or the On-demand Ranging Data characteristic shall be indicated or notified.
6. If the value of the Last Segment bit is 1, then the sequence shall end; otherwise, the sequence shall continue to step 7.
7. The First Segment bit of the Segmentation Header field shall be set to a value of 0.
8. If the number of octets remaining to be sent can be sent in a single additional segment of the Real-time Ranging Data characteristic or the On-demand Ranging Data characteristic, then the Last Segment bit of the Segmentation Header field shall be set to a value of 1; otherwise, it shall remain set to a value of 0.
9. The value of the Rolling Segment Counter shall be incremented by 1.
10. The next octets of the contents of the data to be sent shall be used to fill the characteristic message, in order, consisting of up to (ATT_MTU-4) octets.
11. The sequence shall be repeated from Step 3.

The Rolling Segment Counter shall be set to 0 under the following two conditions:

- When RAS is initialized (e.g., upon connection to the client)
- When the first CS Subevent Result for a new CS Procedure is received from the local Core Controller and the RAS Server is about to send the first segment

The Rolling Segment Counter shall then be continuously incremented starting from 0. When the Rolling Segment Counter reaches 63, the Rolling Segment Counter shall roll over to 0 the next time it is incremented.

Figure 3.1 shows an overview of how Ranging Data Body, Ranging Header, Subevent Header, and Subevent Data are segmented. As is shown in Figure 3.1, the segmentation of Ranging Data Body can function similarly to a sliding window, meaning that an intermediate segment can start from the middle of Ranging Header, Subevent Header, or Step Data.

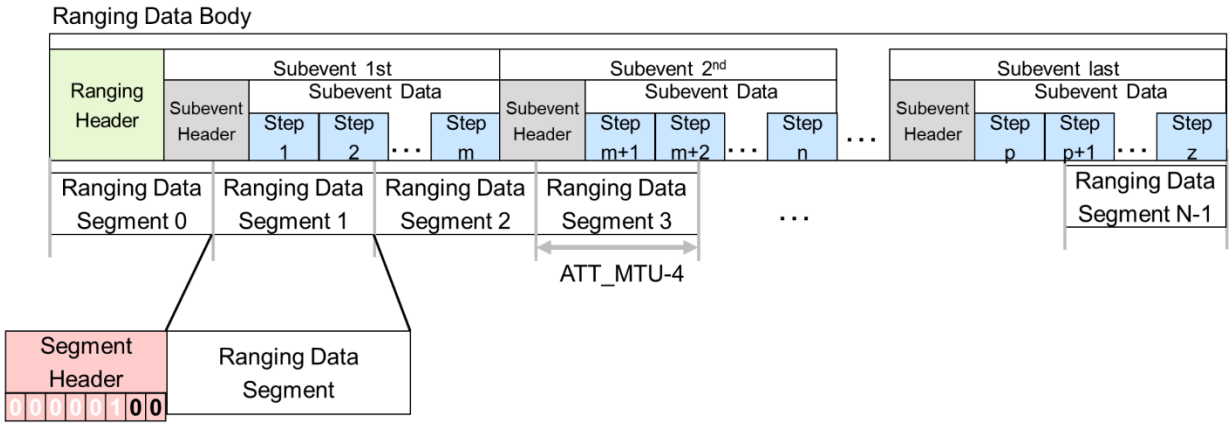

Figure 3.1: Ranging Data segments

3.2.3 Real-time Ranging Data

The RAS Server may support notifications and indications for Real-time Ranging Data.

The Real-time Ranging Data characteristic is used to report received Ranging Data to the client using indications or notifications.

The Ranging Data is reported in real time as soon as it is received from the local Core Controller, meaning that the RAS Server shall start sending indications or notifications once the entire CS Subevent Result for each complete CS Subevent from the local Core Controller is received or once all CS Subevent Results for the entire CS Procedure are received.

3.2.3.1 Real-time Ranging Data behavior

The Real-time Ranging Data characteristic is used by the RAS Server to send generated Ranging Data to the client using indications or notifications.

The RAS Server shall use indications or notifications for sending a Real-time Ranging Data exchange (see Section 3.2.3.1). The client can enable notifications or indications by subscribing to either notifications or indications of the Real-time Ranging Data characteristic by writing to the CCC descriptor associated with the Real-time Ranging Data characteristics.

If the RAS Server supports simultaneous enabling of indications and notifications of the Real-time Ranging Data characteristic, and the client enabled both indications and notifications, then the RAS Server shall use notifications to transfer Real-time Ranging Data in a segmented fashion.

When the client enables Real-time Ranging Data, the client interaction with the RAS Control Point is limited to Ranging Data filtering configuration only (see Section 3.3).

If a portion of unread Ranging Data or the entire unread Ranging Data is overwritten by new Ranging Data, then the RAS Server shall not indicate or notify the Ranging Data Overwritten characteristic (see Section 3.5) and shall start indicating or notifying the new Ranging Data.

When the client enables Real-time Ranging Data reporting, Ranging Data shall be deleted from the RAS Server after it is indicated or notified.

3.2.4 On-demand Ranging Data

The RAS Server shall support notifications and indications for On-demand Ranging Data.

The On-demand Ranging Data characteristic is used to report Ranging Data on demand to the client using the RAS Control Point procedure.

3.2.4.1 On-demand Ranging Data behavior

The On-demand Ranging Data characteristic shall be indicated or notified to the client, in a segmented fashion, as the response to a RAS Control Point command from the client to retrieve the pending Ranging Data from the RAS Server (see Section 3.3.2.1).

The RAS Server shall use indications or notifications for sending an On-demand Ranging Data exchange (see Section 3.2.4.1). The client can enable notifications or indications by subscribing to either notifications or indications of the On-demand Ranging Data characteristic by writing to the CCC descriptor associated with the On-demand Ranging Data characteristics.

If the RAS Server supports simultaneous enabling of indications and notifications of the On-demand Ranging Data characteristic, and the client enabled both indications and notifications, then the RAS Server shall use notifications to transfer On-demand Ranging Data in a segmented fashion.

If a portion of unread Ranging Data or the entire unread Ranging Data is overwritten by new Ranging Data, then the RAS Server shall indicate or notify Ranging Data Overwritten (see Section 3.5).

When the client enables On-demand Ranging Data reporting, Ranging Data shall be deleted from the RAS Server after the client writes the ACK_Ranging_Data command to the RAS Control Point (see Section 3.3.2.2).

3.3 RAS Control Point

The RAS Control Point characteristic allows the client to write commands to the RAS Server and to receive indications from the RAS Server. The On-demand Ranging Data can be retrieved using a Ranging Counter that is indicated beforehand by the RAS Server using the Ranging Data Ready indication. In addition, it allows the client to update the RAS Server that all the Ranging Data notifications have been received and to request retransmission of lost Ranging Data segments.

The structure of this characteristic is stated in Table 3.9.

Field	Data Type	Size (in octets)	Description
Op Code	uint8	1	See Section 3.3.1.
Parameter	struct	Variable	See Section 3.3.1.

Table 3.9: Structure of the RAS Control Point characteristic

3.3.1 RAS Control Point Op Codes and Parameters requirements

Table 3.10 and Table 3.11 show the detailed requirements on RAS Control Point Op Codes and Parameters for Operations and Responses.

Operations Commands				
Op Code	**Op Code Requirement**	**Parameter**		
		#1	**#2**	**#3**
Get_Ranging_Data (0x00)	M	uint16 Ranging Counter	–	–
ACK_Ranging_Data (0x01)	M	uint16 Ranging Counter	–	–
Retrieve_Lost_ Ranging_Data_ Segments (0x02)	O	uint16 Ranging Counter	uint8 First Segment Index	uint8 Last Segment Index

Operations Commands				
Op Code	**Op Code Requirement**	**Parameter**		
		#1	**#2**	**#3**
Abort_Operation (0x03)	O	No Parameter used		
Set_Filter (0x04)	O	uint16 Filter Configuration: Bits 0-1: Mode Bits 2-15: Filter bit mask (see Section 3.3.2.4)	–	–

Table 3.10: RAS Control Point Ranging requirements for Operations Commands

Responses				
Op Code	**Op Code Requirement**	**Parameter**		
		#1	**#2**	**#3**
Complete Ranging Data Response (0x00)	M	uint16 Ranging Counter	–	–
Complete Lost Ranging Data Segment Response (0x01)	C.1	uint16 Ranging Counter	uint8 First Segment Index	uint8 Last Segment Index
Response Code (0x02)	M	Response Code Value	–	–

Table 3.11: RAS Control Point Ranging requirements for Responses

C.1: If the Retrieve Lost Ranging Data Segments procedure is supported, then this Op Code is Mandatory.

The Response Code Values associated with Op Code 0x02 are defined in Table 3.12.

Response Code Value	Definition	Description
0x00	Reserved for Future Use	N/A
0x01	Success	Normal response for a successful operation
0x02	Op Code Not Supported	Normal response if an unsupported Op Code is received
0x03	Invalid Parameter	Normal response if Parameter received does not meet the requirements of the service

Response Code Value	Definition	Description
0x04	Success/Persisted	Normal response for a successful write operation where the values written to the RAS Control Point are being persisted
0x05	Abort Unsuccessful	Normal response if a request for Abort is unsuccessful
0x06	Procedure Not Completed	Normal response if unable to complete a procedure for any reason
0x07	Server Busy	Normal response if the Server is still busy with other requests
0x08	No Records Found	Normal response if the requested Ranging Counter is not found
0x09-0xFF	Reserved for Future Use	N/A

Table 3.12: Response Code Values associated with Op Code 0x02

3.3.2 RAS Control Point behavior

The RAS Control Point characteristic can be used to retrieve and acknowledge On-demand Ranging Data and to set the RAS Server configuration. The mechanism to do this is triggered by a write to the RAS Control Point characteristic that includes an Op Code specifying the operation, as defined in Table 3.10.

3.3.2.1 Get Ranging Data procedure

The RAS Server shall support the Get Ranging Data procedure.

When the Get_Ranging_Data Op Code is written to the RAS Control Point, the RAS Server shall indicate or notify the Ranging Data identified by the Ranging Counter in the first Parameter using the On-demand Ranging Data characteristic.

When all Ranging Data for a given request have been indicated or notified by the RAS Server, the RAS Server shall indicate the RAS Control Point with a Complete Ranging Data Response Op Code and shall set the Parameter to the Ranging Counter of the Ranging Data that was indicated or notified.

The RAS Server shall indicate or notify the Ranging Data content using the On-demand Ranging Data characteristic in the order the Ranging Data were received from the local Core Controller.

The RAS Server shall have memory to record at least one complete Ranging Data for one CS Procedure. If a RAS Server only has enough memory for one CS Procedure, then the Ranging Data Overwritten characteristic or a new Ranging Data Ready indication shall be sent once the CS Procedure result is received from local Core Controller. If the RAS Server has enough memory to record Ranging Data of additional CS Procedures, then the RAS Server may wait until the end of the ongoing Ranging Data transfer and then send a new Ranging Data Ready indication (see Section 3.4) to the client.

If the RAS Server cannot locate any Ranging Data matching the requested Ranging Counter, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to No Records Found.

If the operation results in an error condition, then the RAS Server shall indicate the error using the Response Code Op Code and the appropriate Response Code Value in the Parameter for the error condition (see Section 3.3.1).

If the RAS Server needs to interrupt its Ranging Data transfer before completion for any reason except for an Abort Operation request, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Procedure Not Completed. In the event of an Abort_Operation Op Code, see Section 3.3.2.5.

If the client writes any Op Code, except for an Abort_Operation Op Code, to RAS Control Point while an On-demand Ranging Data procedure is ongoing, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Server Busy.

3.3.2.2 ACK Ranging Data procedure

The RAS Server shall support the ACK Ranging Data procedure.

The ACK_Ranging_Data command has one Parameter, the Ranging Counter, to acknowledge the Ranging Data that was received by the client.

When the ACK_Ranging_Data Op Code is written to the RAS Control Point, the RAS Server shall locate the Ranging Data matching the requested Ranging Counter. If the RAS Server cannot locate any Ranging Data matching the Ranging Counter of the request, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and Response Code Value in the Parameter set to No Records Found. Otherwise, the RAS Server shall delete all On-demand Ranging Data matching the requested Ranging Counter.

The RAS Server shall indicate this characteristic with a Response Code Value of Success after the Ranging Data was successfully deleted from the database. If the operation results in an error condition, then the error shall be indicated using the Response Code Op Code and the appropriate Response Code Value in the Parameter for the error condition (see Section 3.3.1).

3.3.2.3 Retrieve Lost Ranging Data Segments procedure

The RAS Server may support the Retrieve Lost Ranging Data Segments procedure.

The client uses the Retrieve_Lost_Ranging_Data_Segments Op Code to ask for retransmission of segments it failed to receive only when the RAS Server operates in On-demand Ranging Data mode.

The Retrieve_Lost_Ranging_Data_Segments Op Code has three Parameters: the Ranging Counter, the First Segment Index, and the Last Segment Index, which the client uses to specify the requested Segment Indexes from Ranging Data associated with a Ranging Counter.

When the Retrieve_Lost_Ranging_Data_Segments Op Code is written to the RAS Control Point, the RAS Server shall locate the Ranging Data matching the requested Ranging Counter and Segment Indexes and shall indicate or notify records using the On-demand Ranging Data characteristic.

If the client asks for a single Segment Index, then both the First Segment Index field and the Last Segment Index field are set to that specific requested Segment Index.

If the client does not know the Last Segment Index value (i.e., when the last segment was lost), then the client can write the value 0xFF in the Last Segment Index parameter to request all remaining segments starting from the First Segment Index. If the client writes the value 0xFF in the Last Segment Index, then

the RAS Server shall replace the Last Segment Index value written by the client with the Rolling Segment Counter value of the last segment transmitted by the RAS Server.

If the RAS Server cannot locate any Ranging Data matching the Ranging Counter and Segment Indexes of the request, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and Response Code Value in the Parameter set to No Records Found.

The RAS Server shall process the Retrieve_Lost_Ranging_Data_Segments Op Code only if the Get_Ranging_Data Op Code is already written to the RAS Control Point for the same Ranging Counter and the Complete_Ranging_Data Response is already sent to the client. Otherwise, the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and Response Code Value in the Parameter set to Invalid Parameter.

When all requested segments for a given request have been indicated or notified by the RAS Server, the RAS Server shall indicate the RAS Control Point with a Complete Lost Ranging Data Segment Response Op Code and the Parameters set to the Ranging Counter, the First Segment Index, and the Last Segment Index that was sent. The RAS Server shall ignore a new Retrieve_Lost_Ranging_Data_Segments request while a re-transmission is in process.

3.3.2.4 Ranging Data filtering procedure

The RAS Server may support the Ranging Data filtering procedure.

The Ranging Data contains information that might not be needed for the ranging session. To speed up data processing and transfer, a filter mechanism is provided via the RAS Control Point. By writing the Set_Filter Op Code to the RAS Control Point, the client can configure the RAS Server to send only a subset of the Ranging Data.

For default filter settings, all filter bits shall be set to 1 (enabled) for all CS Step mode type filters.

The RAS Server shall apply filter settings written by the client only before the client has enabled Ranging Data notifications or indications (either in the Real-time Ranging Data characteristic or On-demand Ranging Data characteristic).

The filter settings shall be persistent for the duration of the connection.

The RAS Server should store the filter settings in persistent storage for the duration of the bond with the client. If the RAS Server stores the filter settings for the duration of the bond, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Success/Persisted. Otherwise, if filter settings are persistent for the connection only, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Success.

Any filter settings written by the client after Ranging Data notifications or indications were enabled shall not be processed, and the RAS Server shall respond with Response Code Op Code and a Response Code Value in the Parameter set to Op Code Invalid Parameter, as defined in Table 3.12.

The RAS Server shall support setting a separate filter for each CS Step mode type (see Volume 6, Part H, Section 4.3 in [1]).

After the ACL disconnection, if the RAS Server does not support filter settings persistence for the duration of the bond with the client, then the RAS Server shall delete the filter configuration set by the client by setting all filter bits to 1 (enabled) for all CS Step mode type filters.

The RAS Server shall only send Ranging Data to the client where the corresponding filter bit is set to 1 and shall not send data where the corresponding filter bit is set to 0. Table 3.13 captures the filter bits that can be set for each Step mode type, to be used with the Set_Filter Command Op Code and the Filter bit mask field in Parameter #1 (see Table 3.10). The parameters used for each mode are defined in Volume 4, Part 4, Section 7.7.65.44 in [1].

The RAS Server shall ignore RFU bits.

Step mode type	Bit	Parameter Name
0	0	Packet_Quality
	1	Packet_RSSI
	2	Packet_Antenna
	3	Measured_Freq_Offset
	4-13	RFU
1	0	Packet_Quality
	1	Packet_NADM
	2	Packet_RSSI
	3	ToD_ToA
	4	Packet_Antenna
	5	Packet_PCT1
	6	Packet_PCT2
	7-13	RFU
2	0	Antenna_Permutation_Index
	1	Tone_PCT[k]
	2	Tone_Quality_Indicator[k]
	3	Antenna Path_1
	4	Antenna Path_2
	5	Antenna Path_3
	6	Antenna Path_4
	7-13	RFU

Step mode type	Bit	Parameter Name
3	0	Packet_Quality
	1	Packet_NADM
	2	Packet_RSSI
	3	ToD_ToA
	4	Packet_Antenna
	5	Packet_PCT1
	6	Packet_PCT2
	7	Antenna_Permutation_Index
	8	Tone_PCT[k]
	9	Tone_Quality_Indicator[k]
	10	Antenna Path_1
	11	Antenna Path_2
	12	Antenna Path_3
	13	Antenna Path_4

Table 3.13: Filter bits for each Step mode type

3.3.2.5 Abort Operation procedure

The RAS Server may support the Abort Operation procedure.

When the Abort Operation Op Code is written to the RAS Control Point, the RAS Server shall stop any RAS Control Point processes that are in progress and shall flush any pending Ranging Data segments that belong to the Ranging Counter that is aborted.

Once all RAS Control Point processes are stopped, the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Success.

If the operation results in an error condition, then the RAS Server shall indicate the error using the Response Code Op Code and the appropriate Response Code Value in the Parameter for the error condition (see Section 3.3.3).

3.3.3 RAS Control Point error handling procedures

If the RAS Server is unable to complete a procedure defined in Section 3.3.2 for any reason not covered elsewhere in this section, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Procedure Not Completed.

If the RAS Server is unable to process the Abort Operation procedure for any reason not stated elsewhere in this section, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and Response Code Value in the Parameter set to Abort Unsuccessful.

If a request with an Op Code other than Abort Operation is written to the RAS Control Point while the RAS Server is performing a previously triggered RAS Control Point procedure (i.e., resulting from invalid client behavior), then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Server Busy.

If a request with any Op Code that was written to the RAS Control Point characteristic includes a Parameter that uses a Parameter of the wrong length, or the wrong number of Parameters, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Invalid Parameter.

If the Op Code that was written to the RAS Control Point characteristic is not supported by the RAS Server, then the RAS Server shall indicate the RAS Control Point with a Response Code Op Code and a Response Code Value in the Parameter set to Op Code Not Supported.

3.3.4 RAS Control Point procedure timeout and failure

In the context of the RAS Control Point characteristic, an On-demand Ranging Data procedure is started when a write to the RAS Control Point characteristic is successfully completed. When an On-demand Ranging Data procedure is completed, the RAS Server indicates the RAS Control Point characteristic with the Op Code set to the corresponding Response Code.

A Get Ranging Data procedure may consist of multiple characteristic indications or notifications of the On-demand Ranging Data characteristic followed by an indication of the RAS Control Point. When the RAS Server transmits a Complete Ranging Data Response indication or a Complete Lost Ranging Data Segment Response indication of the RAS Control Point characteristic, the response shall be considered to have timed out if the ACK_Ranging_Data command is not received within 5 seconds. If a timeout occurs, then the RAS Server shall consider the RAS Control Point procedure to have failed.

If the connection to the client is lost during a RAS Control Point procedure, then the procedure shall be considered to have failed and shall not resume upon the next connection.

3.4 Ranging Data Ready

The Ranging Data Ready characteristic shall be used by the RAS Server to inform the client of the availability of Ranging Data. The Ranging Data Ready characteristic shall be used when the RAS Server is configured to operate in the On-demand Ranging Data mode.

3.4.1 Ranging Data Ready format

The Ranging Data Ready characteristic has the format defined in Table 3.14.

Field	Requirement	Data Type	Size (in octets)	Description
Ranging Counter	M	uint16	2	The Ranging Counter of the completed CS Procedure

Table 3.14: Ranging Data Ready characteristic

3.4.2 Ranging Data Ready behavior

When the CS Procedure is completed or multiple CS Subevent Results are received from the local Core Controller, and the client enabled Ranging Data Ready indications, or notifications, if supported, then the RAS Server shall send an indication or a notification to the client, which includes the Ranging Counter associated with the CS Procedure.

If the RAS Server supports simultaneous enabling of indications and notifications of the Ranging Data Ready characteristic, and the client enabled both indications and notifications, then the RAS Server shall use indications to report a Ranging Data Ready event.

If the RAS Server supports the read operation for the Ranging Data Ready characteristic, then the Ranging Counter value shall be the Ranging Counter of the most recent completed CS Procedure. If no CS Procedure was completed during the connection, then the Ranging Counter value shall be 0.

3.5 Ranging Data Overwritten

The Ranging Data Overwritten characteristic shall be used when the RAS Server is configured to operate in the On-demand Ranging Data mode and pending unread Ranging Data is overwritten by new Ranging Data.

3.5.1 Ranging Data Overwritten format

The Ranging Data Ready characteristic has the format defined in Table 3.15.

Field	Requirement	Data Type	Size (in octets)	Description
Ranging Counter	M	uint16	2	Ranging Counter of the CS Ranging Data that was overwritten

Table 3.15: Ranging Data Overwritten characteristic

3.5.2 Ranging Data Overwritten behavior

When the Ranging Data Ready Overwritten characteristic is configured for indications or notifications, if supported, then the RAS Server shall indicate or notify the overwriting of an unread Ranging Data to the client. This indication or notification means that the unread Ranging Data for the CS Procedure was overwritten, and the RAS Server has used the resources for Ranging Data that are more recent.

If a RAS Server supports simultaneous enabling of indications and notifications of the Ranging Data Overwritten characteristic, and the client enabled both indications and notifications, then the RAS Server shall use indications to report a Ranging Data Overwritten event.

If the RAS Server supports the read operation for the Ranging Data Overwritten characteristic, then the Ranging Counter value shall be the Ranging Counter of the most recent CS Procedure for which Ranging Data was overwritten. If no Ranging Data was overwritten during the connection, then the Ranging Counter value shall be 0.

4 SDP interoperability

RAS is not exposed over Basic Rate/Enhanced Data Rate (BR/EDR).

5 Acronyms and abbreviations

Acronym/Abbreviation	Meaning
ACL	Asynchronous Connection-oriented logical transport
ATT	Attribute Protocol
BR/EDR	Basic Rate/Enhanced Data Rate
CCC	Client Characteristic Configuration
CS	Channel Sounding
dBm	decibels referenced to 1 milliwatt
GSS	GATT Specification Supplement
HCI	Host Controller Interface
L2CAP	Logical Link Control and Adaptation Protocol
LE	Low Energy
LSO	least significant octet
MSO	most significant octet
MTU	Maximum Transmission Unit
ppm	parts per million
PBR	phase-based ranging
RAS	Ranging Service
RF	radio frequency
RFU	Reserved for Future Use
RTT	round-trip time
UUID	Universally Unique Identifier

Table 5.1: Acronyms and abbreviations

6 References

[1] Bluetooth Core Specification, Version 6.0 or later

[2] GATT Specification Supplement, https://www.bluetooth.com/specifications/gss/

[3] Bluetooth Core Specification Supplement, Version 12 or later

[4] Bluetooth Assigned Numbers, https://www.bluetooth.com/specifications/assigned-numbers/