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 the ranging result from the remote device and to configure the ranging parameters. By enabling high-accuracy distance measurement between Bluetooth devices, new user scenarios are possible.

Contents

1 Introduction

This document specifies the Ranging Service (RAS), a Generic Attribute Profile (GATT) service intended to be instantiated in the GATT Server and accessed by a GATT Client. The main functionality of RAS is to provide ranging results from the GATT Server to the GATT Client.

As specified in Core Channel Sounding (CS) [5], the CS Controller on the GATT Server (i.e., RAS Server) side shall have either the Initiator or the Reflector role defined. The Initiator and the Reflector roles are independent from the Central GAP and the Peripheral GAP roles, which means that the Controller that implements the Central role can support either the Initiator or the Reflector role.

The Initiator and Reflector run a CS Procedure in the Controller, 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 the Reflector [5].

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. Separate CS Subevent Result information might be generated per CS Subevent. Figure 1.1 shows the relationship between procedures, events, subevents, and steps [5].

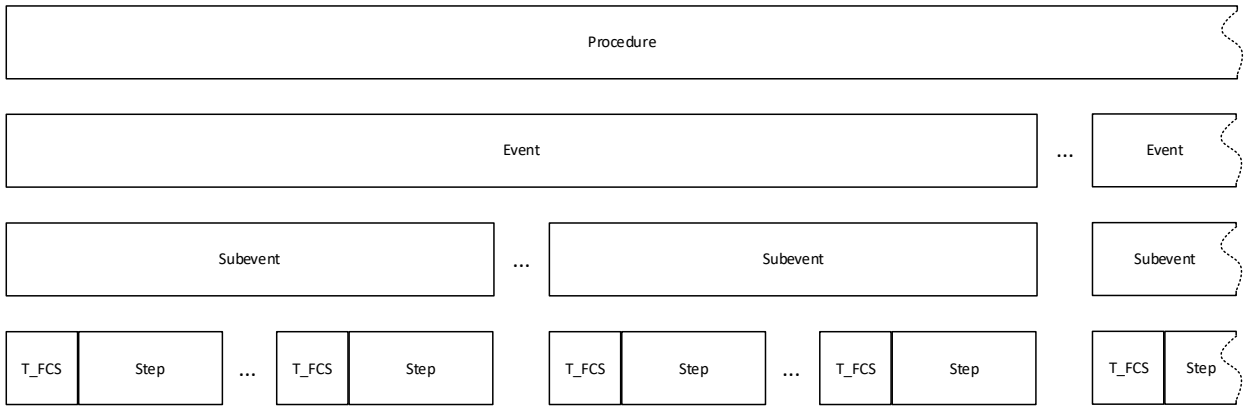

Figure 1.1: CS Procedure/Event/Subevent/Step hierarchy

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

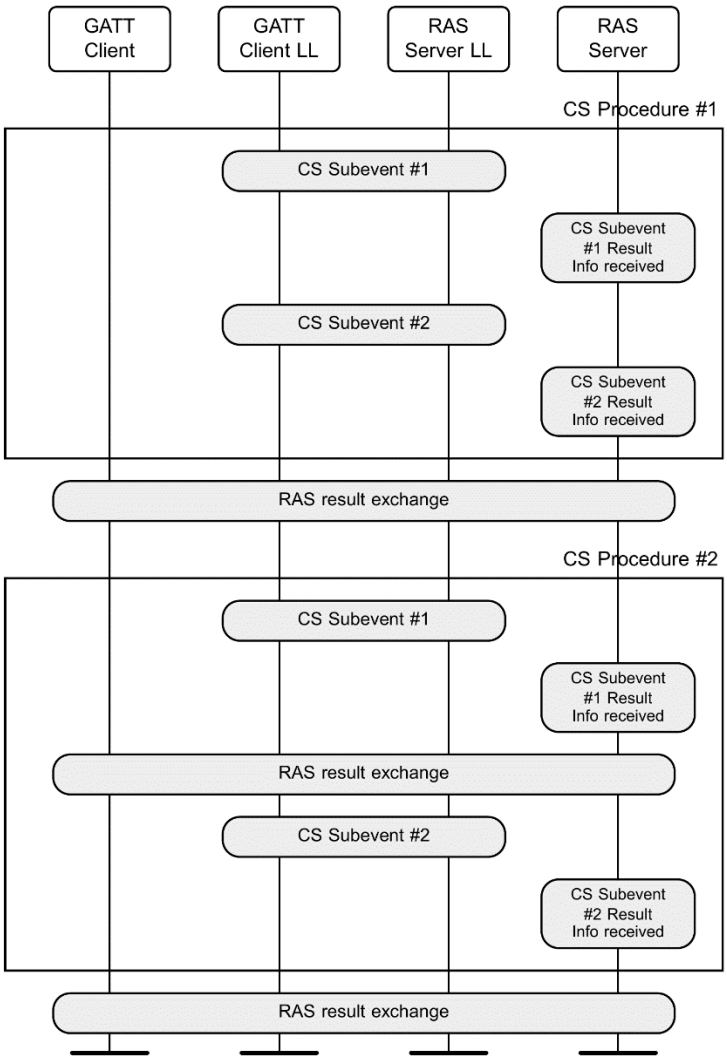

Figure 1.2: The full end-to-end CS flow diagram including RAS result exchange

The host on the RAS Server side will receive the CS Ranging Data for each CS Subevent from the local Controller [6] either while the CS Procedure is running or after it is finished. The RAS Server shall send the CS Ranging Data to a GATT Client per a CS Procedure or per a CS Subevent. The total size of the CS Ranging Data for one procedure can reach up to ~5KB. One of the main objectives of RAS is to specify an optimized method for forwarding the CS Ranging Data from the RAS Server to a GATT 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 5.4 [1] or later.

2.3 Transport dependencies

RAS only works over Low Energy (LE) transport but can be discoverable over BR/EDR transport.

2.4 Attribute Protocol Application error code

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

Name	Error Code	Description
Procedure Already In Progress	0xFE	Common profile error code used in CSS

Table 2.1: Attribute Protocol 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	C.1
Characteristic Value Indication	M
Read Characteristic Descriptors	M
Write Characteristic Descriptors	M
Write Characteristic Value	M

Table 2.2: GATT sub-procedure requirements

C.1: Mandatory if one of the Ranging Data characteristics supports notifications.

2.6 Declaration

RAS shall be instantiated as a primary service. The service's UUID shall be set to «Ranging Service» as specified in [4].

2.7 Behavior

RAS enables a GATT Client to read the Ranging Data from a RAS Server on which the RAS is exposed. In RAS, there are five characteristics that support notification or indication:

- Real-time Ranging Data
- On-demand Ranging Data
- RAS-CP
- Ranging Data Ready
- Ranging Data Overwritten

A GATT Client can be subscribed to these characteristics by writing to the Client Characteristic Configuration (CCC) descriptor associated with these characteristics.

RAS is specified to be implemented on an RAS Server that receives Ranging Data from the local Controller. RAS distinguishes two categories of Ranging Data exchange:

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

A RAS Server shall transfer Ranging Data in order of time, with the oldest being sent first. This requirement applies to both an on-demand Ranging Data exchange that is transferred in an RAS-CP process as well as to a Real-time Ranging Data exchange. In addition, upon the readiness of the first Subevent Result from the local Controller, the RAS server may begin transmitting notifications/indications and send the remaining Subevent Results after the Subevent Results have arrived.

The RAS Server shall use either indications or notifications for sending a Real-time Ranging Data exchange or an On-demand Ranging Data exchange. RAS shall expose the characteristics listed in Section 3 and in Table 3.1. These characteristics may be notified, indicated, and written (where the characteristic properties allow) to receive CS Ranging Data. Where a characteristic can be indicated or notified, a Client Characteristic Configuration descriptor must be included in that characteristic.

Using the RAS-CP process, a GATT Client can request missing segments associated with a particular Ranging Counter only for On-demand Ranging Data. The RAS Server shall send the requested segments. Once retransmission is completed, the RAS Server shall use the RAS-CP process to indicate the end of the retransmission process.

2.7.1 Role

RAS facilitates a GATT Client in reading the Ranging Data from a RAS Server on which the service is exposed. Therefore, any references in this document to the "server" are to the RAS Server that exposes this service.

Requirements for the behavior of a GATT Client may be specified in a separate profile specification.

2.7.2 RAS behavior

The RAS Server shall receive the Ranging Data from the local Controller. After the Ranging Data for one CS Procedure is received, the RAS Server has two behaviors:

1. The RAS Server sends a Ranging Data Ready indication to the GATT Client with a CS Ranging Counter. The GATT Client sends a Get_Ranging_Data command to get the CS Ranging Data on-demand from the RAS Server.

2. The RAS Server uses the Real-time Ranging Data characteristic to report generated Ranging Data to a GATT Client using indications or notifications.

2.7.2.1 RAS On-demand behavior

As shown in Figure 2.1, when the Get Ranging Data Op Code is written to the RAS-CP, 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 have been indicated or notified by the RAS Server, the RAS Server shall indicate the RAS-CP with a Complete Ranging Data Response Op Code and the Parameter set to the Ranging Counter reported. As the final response, the GATT Client will send the ACK_Ranging_Data command. After the ACK_Ranging_Data command is written, the RAS Server should remove the Ranging Data that was acknowledged from its storage.

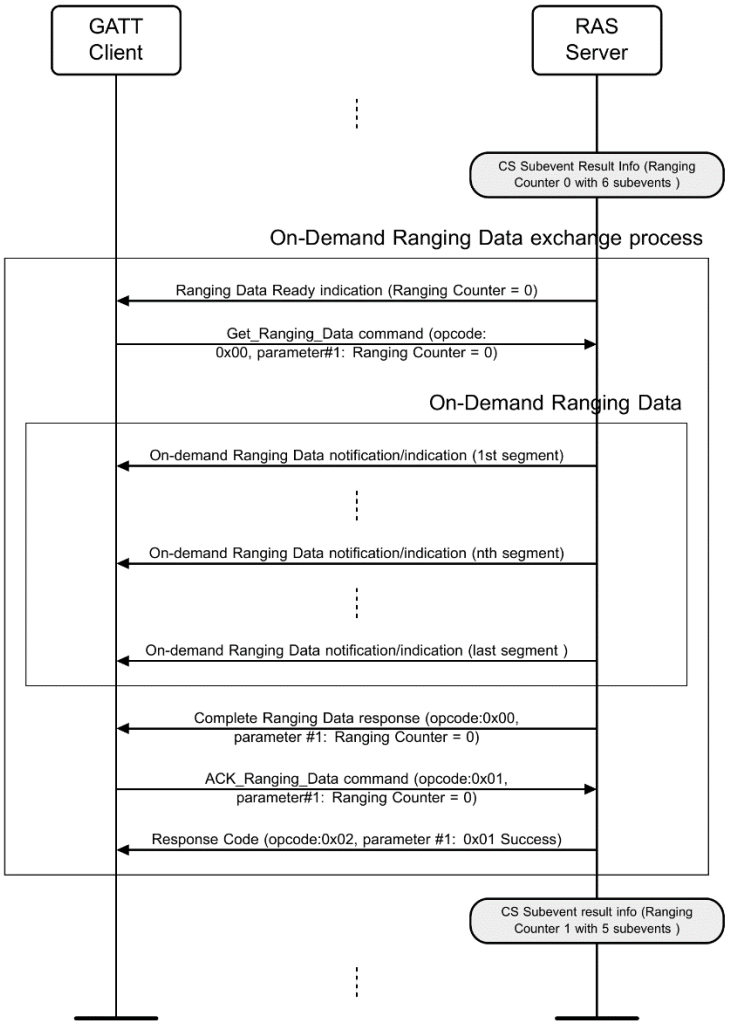

Figure 2.1: Message sequence chart for On-demand Ranging Data using RAS-CP

2.7.2.2 RAS real-time behavior

As shown in Figure 2.2, the Ranging Data is reported in a real-time manner as soon as the CS Subevent result is received from the local Controller, in other words, the Real-Time Ranging Data notifications or indications may start while the CS Procedure is still ongoing.

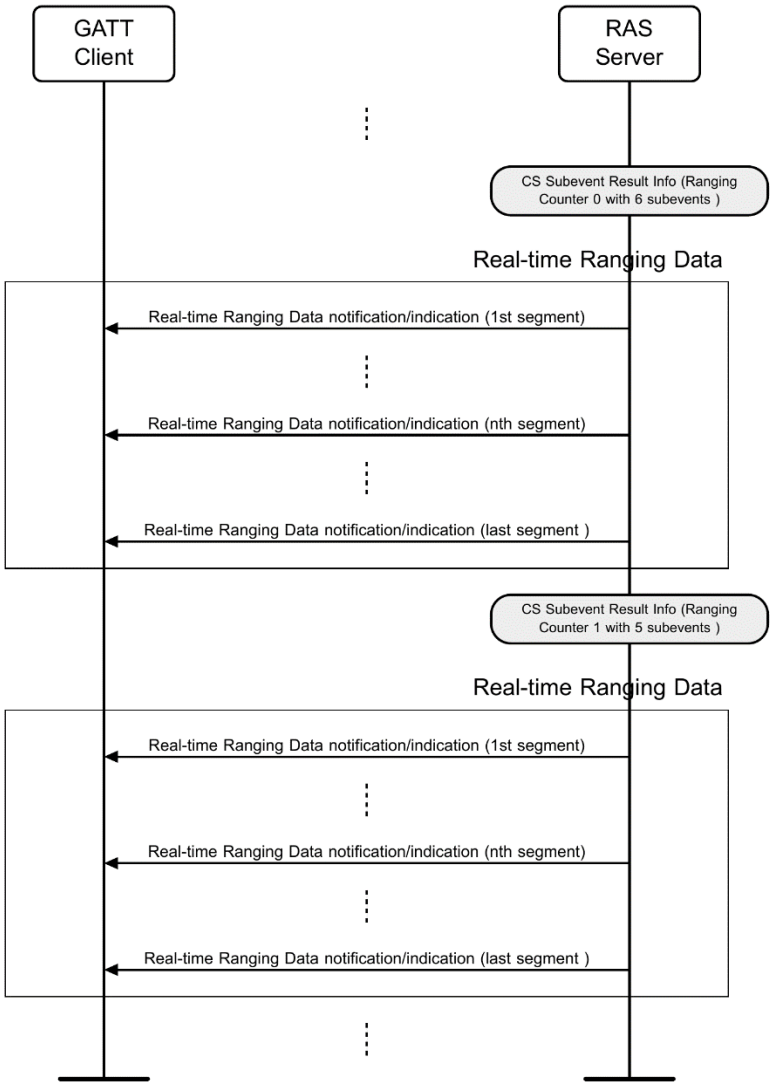

Figure 2.2: Message sequence chart for Real-time Ranging Data

2.7.2.3 RAS Ranging Data overwritten and segment loss behavior

The RAS Server shall store the data for at least one CS Procedure, where each procedure includes up to 32 Subevents Result and 256 CS steps. The RAS Server may queue more than one CS Ranging Data (i.e., the entire CS Procedure results). If the RAS Server is running out of memory, after the first Subevent Result for the new procedure is received, the entire previous Ranging Data shall be deleted.

When the RAS Server overwrites the unread CS Ranging Data with the new CS Ranging Data, it shall inform the GATT Client with a Ranging Data Overwritten indication/notification, as shown in Figure 2.3.

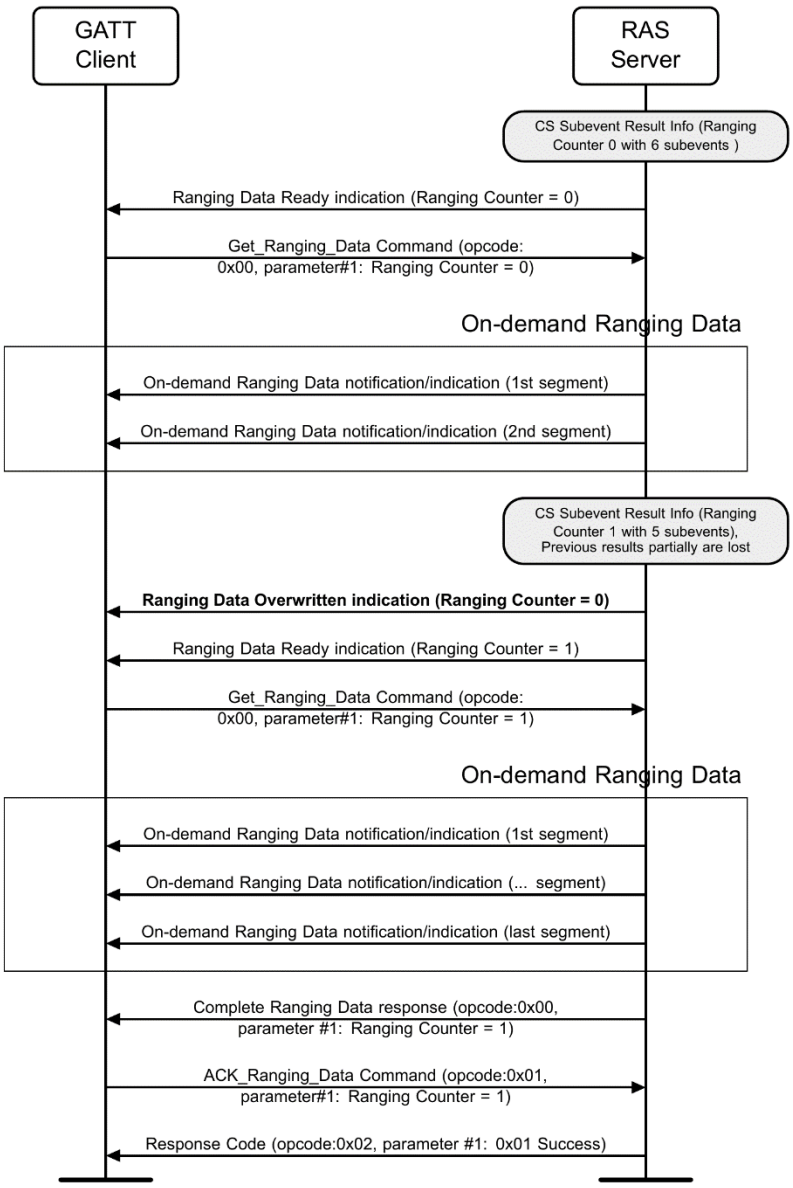

Figure 2.3: Ranging Data overwritten and the RAS Server sends a Ranging Data Overwritten indication

Figure 2.4 shows an example of an On-demand Ranging Data indication/notification segment loss. In this example, the indication/notification with Rolling Segment Counter = 10 is lost and the GATT 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/notification with a specific segment counter and sends a Complete Lost Ranging Segment Response to indicate the end of the process. Finally, the GATT Client acknowledges the reception of complete Ranging Data by writing the ACK On-demand Ranging Data Op Code to the RAS-CP.

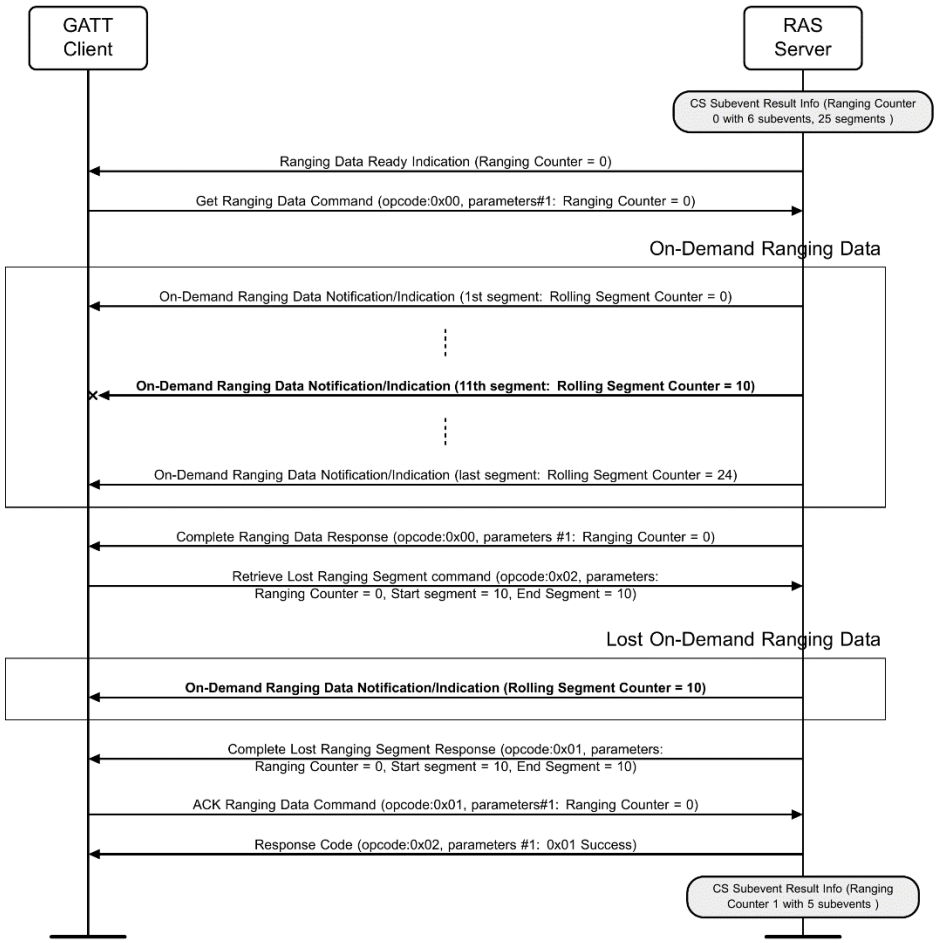

Figure 2.4: On-demand Ranging Data Segment failure and retrieval lost segment process for On-demand CS Ranging Data using RAS-CP

3 Service characteristics

The RAS exposes the characteristics listed in Table 3.1. These characteristics may be notified, indicated, and written (where the characteristic properties allow) to receive the CS Ranging Data. Where a characteristic can be indicated or notified, a Client Characteristic Configuration (CCC) descriptor must be included in that characteristic.

Characteristic Name	Requirement	Mandatory Properties	Optional Properties	Security Permissions
RAS Features	M	Read	None	Encryption required
Real-time Ranging Data	O	Indicate or notify	None	Encryption required
On-demand Ranging Data	M	Indicate or notify	None	Encryption required
RAS Control Point (RAS-CP)	M	Write, Indicate	None	Encryption required
Ranging Data Ready	M	Indicate or notify	None	Encryption required
Ranging Data Overwritten	M	Indicate or notify	None	Encryption required

Table 3.1: Characteristics for use with RAS

3.1 RAS Features

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

Bit	Definition
0	Real-time Ranging Data
1	Retrieve Lost Ranging Data Segments
2	Abort Operation
3	Filter Ranging Data
4	PCT Phase Format
5-31	RFU

Table 3.3: RAS Features field

3.1.2 RAS Features behavior

When read, the RAS Features characteristic returns a value that is used by a GATT Client to determine the supported features of the RAS Server.

All specified RAS Feature bits in this specification (i.e., bits 0 to 4) shall retain their allocated position during the lifetime of a device.

3.2 Real-time Ranging Data

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

The Ranging Data are reported real-time as soon as they are received from the local Controller, meaning that the RAS Server may start sending indications or notifications once the entire CS Subevent Result for one complete CS Subevent from local Controller is received, or once all CS Subevent Results for the entire CS Procedure are received. The reported data shall only contain the data required by the filter if a Ranging Data Filter has been set by the GATT Client via the RAS-CP filter procedure.

A 1-byte segmentation scheme is used to support values that do not fit in a single Maximum Transfer Unit (MTU).

3.2.1 Real-time Ranging Data format

The Real-time Ranging Data characteristic has the format stated 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 3.2.2.1.

Table 3.4: Real-time Ranging Data characteristic format

3.2.1.1 Segmentation Header

Table 3.5 defines the values of the Segmentation Header field. The RAS Server shall use these values to provide information to the GATT 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 content that should be concatenated by the GATT Client. 0 = False 1 = True

Bit Number	Definition
1	Last Segment: The characteristic contains the last segment of content that should be concatenated by the GATT Client. 0 = False 1 = True
2-7	Rolling Segment Counter: 0 to 63 The Rolling Segment Counter is incremented per segment during a connection. If the Rolling Segment Counter is equal to 63, the counter rolls over to 0 when it is next incremented.

Table 3.5: Segmentation Header structure

3.2.1.2 Ranging Data Body

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 (CSProcCount) provided by the Controller
Configuration ID	4	CS configuration identifier Range: 0 to 3
Selected TX power	8	Transmit power level used for CS procedure Range: -127 to 20 Units: dBm

Field	Size (bits)	Description
Antenna Paths Mask	6	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 4-5: RFU
PCT Format	2	Phase/IQ format (IQ=0, phase = 1, RFU: 2-3)

Table 3.7: Ranging Header structure

Because there may be multiple CS Ranging Data stored in RAS Server, a CS Ranging Counter is used to enable multiple CS Ranging Data to be identified individually within a single RAS Server device.

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

	Field	Size (bits)	Description
Subevent Header	Start ACL Conn 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 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 = Reserved for future use
	Subevent Done Status	4	0x0 = All results complete for the CS Subevent 0xF = Current CS Subevent aborted. All other values = Reserved for future use
	Ranging Abort Reason	4	Indicates the abort reason when Procedure Done Status 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 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 = Reserved for future use
	Subevent Abort Reason	4	Indicates the abort reason when Subevent Done Status 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) received 0x3 = Abort because of scheduling conflicts or limited resources 0xF = Abort because of unspecified reasons All other values = Reserved for future use
	Reference Power Level	8	Reference power level. Range: -127 to 20. Units: dBm
	Num Steps Reported	8	Number of steps in the CS Subevent for which results are reported
Subevent Data	Step_Mode [i]	Num Steps Reported * 8	Bit 0-1: Mode type, Range: 0x00-0x03 Bit 2-6: RFU Bit 7: 1 means Aborted, 0 means Success
	Step_Data [i]	Variable	Mode- and role-specific information being reported

Table 3.8: Subevent Header and Data structure

A RAS Server may have zero or more CS Subevent Results, up to a maximum of 32. The CS Subevent Data can have 1-3 Mode 0 step results and multiple non-Mode 0 step results, where the maximum number of steps per CS Subevent is 160 and per CS Procedure is 256 [5].

When no data filtering and Antenna Path filtering are applied, the mode type Step Data is defined as follows:

3.2.1.2.1 Mode type 0

When the mode type is 0 and the role is Initiator, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_RSSI
- Packet_Antenna
- Measured_Freq_Offset (as measured relative to the other device)

When the mode type is 0 and the role is Reflector, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_RSSI
- Packet_Antenna

3.2.1.2.2 Mode type 1

When the mode type is 1 and the role is Initiator, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- ToA_ToD_Initiator
- Packet_Antenna

When the mode type is 1, the role is Initiator, sounding phase-based ranging is supported, and the Round Trip Time (RTT) type contains a sounding sequence, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- ToA_ToD_Initiator
- Packet_Antenna
- Packet_PCT1
- Packet_PCT2

When the mode type is 1 and the role is Reflector, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality

- Packet_NADM
- Packet_RSSI
- ToD_ToA_Reflector
- Packet_Antenna

When the mode type is 1, the role is Reflector, sounding phase-based ranging is supported, and the RTT type contains a sounding sequence, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- ToD_ToA_Reflector
- Packet_Antenna
- Packet_PCT1
- Packet_PCT2

3.2.1.2.3 Mode type 2

When the mode type is 2 and the role is either Initiator or Reflector, the parameters of the ModeRoleSpecificInfo object are as follows:

- Antenna_Permutation_Index
- Tone_PCT[k]
- Tone_Quality_Indicator[k]

3.2.1.2.4 Mode type 3

When the mode type is 3 and the role is Initiator, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- Packet_Antenna
- ToA_ToD_Initiator
- Antenna_Permutation_Index
- Tone_PCT[k]
- Tone_Quality_Indicator[k]

When the mode type is 3, the role is Initiator, sounding phase-based ranging is supported, and the RTT type contains a sounding sequence, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- Packet_Antenna
- Packet_PCT1

- Packet_PCT2
- ToA_ToD_Initiator
- Antenna_Permutation_Index
- Tone_PCT[k]
- Tone_Quality_Indicator[k]

When the mode type is 3 and the role is Reflector, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- Packet_Antenna
- ToD_ToA_Reflector
- Antenna_Permutation_Index
- Tone_PCT[k]
- Tone_Quality_Indicator[k]

When the mode type is 3, the role is Reflector, sounding phase-based ranging is supported, and the RTT type contains a sounding sequence, the parameters of the ModeRoleSpecificInfo object are as follows:

- Packet_Quality
- Packet_NADM
- Packet_RSSI
- Packet_Antenna
- Packet_PCT1
- Packet_PCT2
- ToD_ToA_Reflector
- Antenna_Permutation_Index
- Tone_PCT[k]
- Tone_Quality_Indicator[k]

3.2.2 Real-time Ranging Data behavior

The Real-time Ranging Data characteristic is used by the RAS Server to send generated CS Ranging results to a GATT Client.

If a RAS Server supports simultaneous enabling of indications and notifications of the Real-time Ranging Data characteristic, the server shall use either indications or notifications (but not both) to report a Real-time Ranging Data.

3.2.2.1 Segmentation

Figure 3.1 shows an overview of how Ranging Data Body, Ranging Header, Subevent Header, and Subevent Data are being segmented. As is shown in the figure, 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.

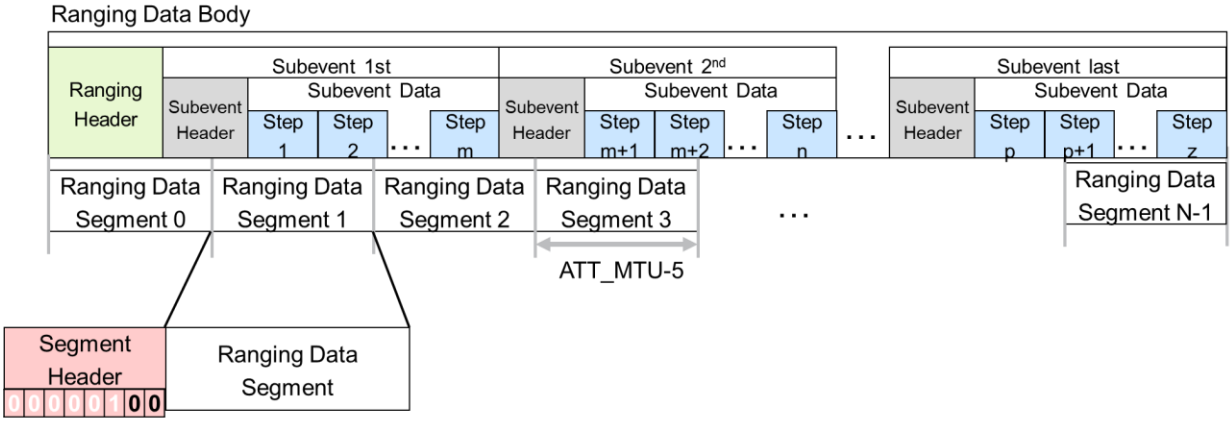

Figure 3.1: Ranging Data segments

If the total size of the received Ranging Data is greater than (ATT_MTU-5), 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-5) rounded up to the nearest integer.

When the Real-time Ranging Data characteristic is configured for indications or notifications via the Client Characteristic Configuration descriptor, the RAS Server receives a command to start sending Real-time Ranging Data and generated Ranging Data is available; this characteristic shall be indicated or notified per segment as described in the following sequence:

1. If N=1, 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, 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-5) octets of the data to be transported shall be used to fill the characteristic message.
5. The Real-time Ranging Data characteristic shall be indicated or notified.
6. If the value of the Last Segment bit is 1, end the procedure at this point; otherwise, 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 notification of the Real-time Ranging Data characteristic, 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-5) octets.
11. Repeat from Step 4.

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

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

The Rolling Segment Counter shall then be incremented starting from 0 continuously without being reset each time that the above sequence is applied. When the Rolling Segment Counter reaches 63, the Rolling Segment Counter shall roll over to 0 the next time that it is incremented.

In Real-time Ranging Data, if a portion or the entire unread Ranging Data is overwritten by new Ranging Data, the RAS server shall not indicate or notify Ranging Data Overwritten and shall start indicating or notifying the new Ranging Data.

Section 3.3 describes the On-demand Ranging Data characteristic, in which the segmentation scheme used to report the On-demand Ranging Data characteristic is the same scheme that is described here for the Real-time Ranging Data characteristic.

3.2.2.2 Real-time Ranging Data reporting

With this strategy, there is no need to use a RAS-CP and an On-demand Ranging Data characteristic, and Ranging Data is deleted from the server after retrieval. Ranging Data is sent to only one GATT Client using indications or notifications of the Real-time Ranging Data characteristic.

3.3 On-demand Ranging Data

The On-demand Ranging Data characteristic is used to report On-demand Ranging Data to a GATT Client using the RAS-CP process.

3.3.1 On-demand Ranging Data format

The On-demand Ranging Data characteristic replicates the format of Real-time Ranging Data stated in Table 3.4.

3.3.2 On-demand Ranging Data behavior

The On-demand Ranging Data characteristic shall be indicated or notified to a GATT Client, in a segmented fashion, as the response to an RAS-CP command from a GATT Client to retrieve the received Ranging Data.

If a server supports simultaneous enabling of indications and notifications of the On-demand Ranging Data characteristic, the server shall use either indications or notifications (but not both) to report the Ranging Data characteristic.

The segmentation scheme used to report the On-demand Ranging Data characteristic is the same scheme that is used for the Real-time Ranging Data characteristic (see Section 3.2.2.1).

3.4 RAS-CP

A RAS Control Point (RAS-CP) characteristic is included as a mandatory characteristic with associated procedures.

The RAS-CP enables only one GATT Client to retrieve On-demand Ranging Data from the RAS Server.

A RAS Server may support both retrieval of On-demand Ranging Data and sending Real-time Ranging Data. However, it might not be able to support both at the same time, because only the On-demand Ranging Data is mandatory (see Section 3.4.4 for the server behavior in that situation).

The RAS-CP characteristic allows a GATT Client to write commands to the RAS Server and to get the segments that it failed to receive. 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 GATT Client to tell the RAS Server that all the Ranging Data notifications are received.

The structure of this characteristic is stated in Table 3.9.

Field	Data Type	Size (in octets)	Description
Op Code	uint8	1	See Section 3.4.2.
Parameter	struct	Variable	See Section 3.4.2.

Table 3.9: Structure of the RAS-CP characteristic

3.4.1 Ranging Data definition

In the context of the RAS, Ranging Data is the CS Procedure results that are received from the CS Controller.

3.4.2 RAS-CP Op Codes and Parameters requirements

Table 3.10 and Table 3.11 show the detailed requirements on RAS-CP Op Codes and Parameters for Operations and Responses. Op Codes that are not present in these tables shall not be supported. The Op Codes for Get Ranging Data have the same requirements that are combined in one row.

Commands				
Op Code	**Op Code Requirement**	**Parameter**		
		#1	**#2**	**#3**
Get_Ranging_Data (0x00)	M	Unit16 Ranging Counter		
ACK_Ranging_Data (0x01)	M	Uint16 Ranging Counter		
Retrieve_Lost_ Ranging_Data_ Segments (0x02)	O	Uint16 Ranging Counter	Uint8 Start segment	Uint8 End segment
Abort_Operation (0x03)	O	No Parameter Used		
Filter (0x04)	O	Mode [2bits]	Bit Mask [14bits]	
PCT_Format (0x05)	O	Phase/IQ format (1bit: IQ=0, phase = 1)		

Table 3.10: RAS-CP Ranging requirements for Operations

Responses				
Op Code	**Op Code Requirement**	**Parameter**		
		#1	**#2**	**#3**
Complete Ranging Data Response (0x00)	M	Unit16 Ranging Counter		
Complete Lost Ranging Data Segment Response (0x01)	C.1	Unit16 Ranging Counter	Uint8 Start Segment	Uint8 End Segment
Response Code (0x02)	M	Response Code Value		

Table 3.11: RAS-CP Ranging requirements for Responses

C.1: If Retrieve Lost Ranging Data Segments is supported, this Opcode 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 successful operation.
0x02	Op Code not supported	Normal response if unsupported Op Code is received.
0x03	Invalid Parameter	Normal response if Parameter received does not meet the requirements of the service (e.g., Null was expected).
0x04	Parameter not supported	Normal response if unsupported Parameter is received.
0x05	Abort unsuccessful	Normal response if 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

3.4.3 RAS-CP behavior

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

3.4.3.1 Get Ranging Data process

When the Get Ranging Data Op Code is written to the RAS-CP, 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-CP with a Complete Ranging Data Response Op Code and the Parameter set to the Ranging Counter reported. Storing more than one Ranging Data is not needed and not mandatory.

The RAS Server shall report the Ranging Data in the order they were received from the local Controller.

The RAS Server shall record at least a complete Ranging Data for one CS Procedure. If a RAS Server only has memory for one procedure, then Ranging Data Overwritten or a new Ranging Data Ready Indication shall be sent once CS Procedure result is received from local Controller. If the RAS Server has enough memory to record Ranging Data of additional CS Procedure, it might wait until the end of the ongoing Ranging Data transfer and then send a new Ranging Data Ready to the GATT Client.

If the RAS Server does not locate any Ranging Data matching the requested Ranging Counter, the server shall indicate the RAS-CP 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 3.4.4).

If the RAS Server needs to interrupt its data transfer before completion for any reason except in the event of an Abort Operation request, the RAS Server shall indicate the RAS-CP 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 command, the procedure terminates immediately without the RAS-CP indicating the Response Code Op Code for this procedure. The RAS Server keeps the On-demand Ranging Data and it can either send the new indication or wait for the GATT Client to send a new Get Ranging Data.

3.4.3.2 ACK Ranging Data process

The RAS Server shall support the ACK Ranging Data process.

When the ACK Ranging Data Op Code is written to the RAS-CP, the RAS Server shall delete all On-demand Ranging Data matching the requested Ranging Counter. Deletion of Ranging Data may be a permanent deletion of Ranging Data from the database. The RAS Server shall indicate this characteristic with a Response Code Value of Success if the Ranging Data were successfully deleted from the database.

The ACK_Ranging_Data command has one Parameter, which is the Ranging Counter, to acknowledge the Ranging Data that was received by the GATT Client.

If the RAS Server does not locate any Ranging Data matching the Ranging Counter of the request, the server shall indicate the RAS-CP with a Response Code Op Code and Response Code Value in the Parameter set to No Records Found.

If the operation results in an error condition, this shall be indicated using the Response Code Op Code and the appropriate Response Code Value in the Parameter for the error condition (see Section 3.4.4).

3.4.3.3 Retrieve Lost Ranging Data Segments process

The GATT Client uses the Retrieve_Lost_Ranging_Data_Segments command to ask for retransmission of failed segments for only On-demand Ranging Data.

When the Gets Lost Ranging Data Segments Op Code is written to the RAS-CP, the RAS Server shall indicate or notify records using the On-demand Ranging Data characteristic. The Retrieve_Lost_Ranging_Data_Segments command has three Parameters for the Ranging Counter, the Start Segment counter, and the End Segment counter. If the GATT Client is asking for a single segment, then both the Start Segment counter field and the End Segment counter field are set to that specific failed segment.

The RAS Server shall respond to the GATT Client if and only if the Get Ranging Data Op Code is already written to the RAS-CP for the same Ranging Counter and the Complete Ranging Data Response is already sent to the GATT Client. The RAS Server shall not accept a new Retrieve Lost Ranging Data Segment request while ongoing On-demand Ranging Data process is in process.

When all requested segments for a given request have been indicated or notified by the RAS Server, the RAS Server shall indicate the RAS-CP with a Complete Lost Ranging Data Segment Response Op Code and the Parameters set to the Ranging Counter, the Start Segment counter, and the End Segment counter that was sent. The RAS Server shall not accept a new Retrieve Lost Ranging Data Segment request while a re-transmission is in process.

3.4.3.4 Ranging Data filtering process

The Ranging Data contains a lot of 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-CP. By using this filter operation, the GATT Client can let the RAS Server know that it only wants a part of the Procedure Ranging Data.

The RAS Server shall apply filter settings written by the GATT Client only before the GATT Client-enabled Procedure Ranging Data notifications or indications (either Real-time or On-demand). Any filter settings written by the GATT Client after Procedure Ranging Data notifications or indications were enabled shall be ignored, and the RAS Server shall respond with Op Code 0x02 and Response Code 0x03 – Invalid Parameter, as defined in Table 3.12.

The RAS Server shall support setting a separate filter for each CS mode. The filter shall be persistent for the entirety of the connection.

The RAS Server shall only send Procedure 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 mode. RFU bits shall be set to 0.

After the ACL disconnection, the RAS Server shall delete the filters set by setting all filter bits to 1 (enabled) for all CS mode filters.

Mode	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
3	0	Packet_Quality
	1	Packet_NADM
	2	Packet_RSSI
	3	Packet_Antenna
	4	Packet_PCT1
	5	Packet_PCT2

	6	ToD_ToA
	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 mode.

3.4.3.5 PCT format process

When the PCT format Op Code is written to the RAS-CP, the RAS Server shall report the PCT in the Ranging Data body as requested. By default, the RAS Server shall report the PCTs in IQ format. If the GATT Client requests the PCT format to be in Phase only and if the RAS Server is supporting it, then it shall report PCT in phase format. Otherwise, if the PCT format Op Code is not supported by the RAS Server, the RAS Server shall indicate the RAS-CP with a Response Code Op Code and a Response Code Value in the Parameter set to Op Code Not Supported.

The RAS Server shall apply PCT format settings written by the GATT Client only before the GATT Client-enabled Procedure Ranging Data notifications or indications (either Real-time or On-demand). Any PCT format settings written by the GATT Client after Procedure Ranging Data notifications or indications were enabled shall be ignored, and the RAS Server shall respond with Op Code 0x02 and Response Code 0x03 – Invalid Parameter, as defined in Table 3.12.

3.4.3.6 Abort Operation procedure

This section is only applicable if the server supports the Abort Operation procedure.

When the Abort Operation Op Code is written to the RAS-CP, the RAS Server shall stop any RAS-CP processes that are in progress.

When all RAS-CP processes have been stopped, the server shall indicate the RAS-CP 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 3.4.4).

3.4.4 RAS-CP error handling procedures

If the RAS Server is unable to complete a procedure defined in Section 3.4.3 for any reason not covered elsewhere in this section, the server shall indicate the RAS-CP 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, the server shall indicate the RAS-CP with a Response Code Op Code and Response Code Value in the Parameter set to Abort unsuccessful.

If the RAS Server is unable to execute an RAS-CP process because Real-time Ranging Data is being transferred and the server cannot support transfers of Real-time Raging Data in parallel with executing RAS-CP process, the server shall indicate the RAS-CP with a Response Code Op Code and a Response Code Value in the Parameter set to Server Busy.

If a request with an Op Code other than Abort Operation is written to the RAS-CP while the RAS Server is performing a previously triggered RAS-CP process (i.e., resulting from invalid GATT Client behavior), the server shall return an error response with an error code of Procedure Already In Progress.

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

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

If the RAS Server gets the Retrieve Lost Ranging Data command while an On-demand Ranging Data process in ongoing, the RAS Server shall indicate the RAS-CP with a Response Code Op Code and a Response Code Value in the Parameter set to Server Busy.

3.4.5 RAS-CP process timeout and failure

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

An On-demand Ranging Data process may consist of multiple characteristic indications or notifications of the On-demand Ranging Data characteristic followed by an indication of the RAS-CP. When the RAS Server transmits an indication of the RAS-CP characteristic, the response is considered to have timed out if the acknowledgment is not received within the process timeout, defined as 30 seconds. If a timeout occurs, the RAS Server shall consider the process to have failed.

If the connection to the GATT Client is lost, the process shall be considered to have failed and shall not resume upon the next connection.

3.5 Ranging Data Ready

When CS Procedure is completed or multiple Subevents Results are received from the local Controller, the RAS Server sends an indication to the GATT Client including the Ranging Counter.

3.5.1 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	Ranging Counter that is completed

Table 3.14: Ranging Data Ready characteristic

3.5.2 Ranging Data Ready behavior

The Ranging Data Ready characteristic is used by the RAS Server to inform the availability of Ranging Data to a GATT Client.

If a server supports simultaneous enabling of indications and notifications of the Ranging Data Ready characteristic, the server shall use either indications or notifications (but not both) to report a Real-time Ranging Data.

3.6 Ranging Data Overwritten

In On-demand Ranging Data using RAS-CP, after an unread Ranging Data is overwritten by the new Ranging Data, the RAS Server sends indication to the GATT Client and indicates that the old Ranging Data is overwritten.

3.6.1 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 procedure that is overwritten

Table 3.15: Ranging Data Overwritten characteristic

3.6.2 Ranging Data Overwritten behavior

When the Ranging Data Ready Overwritten characteristic is configured for indications, the RAS Server shall indicate the overwriting of an unread CS Ranging Data to the GATT Client. This indication means that the unread CS Ranging Data for the procedure has been overwritten, and the RAS Server has released resources.

4 SDP interoperability

If this service is exposed over BR/EDR, it shall have the following SDP record.

Item	Definition	Type	Value	Status
Service Class ID List	–	–	–	M
Service Class #0	–	UUID	«Ranging Service»	M
Protocol Descriptor List	–	Data Element Sequence	–	M
Protocol #0	–	UUID	«L2CAP»	M
Parameter #0 for Protocol #0	Protocol/Service Multiplexer (PSM)	Uint16	PSM = Attribute Protocol (ATT)	M
Protocol #1	–	UUID	«ATT»	M
Additional Protocol Descriptor List	–	Data Element Sequence	–	C.1
Protocol Descriptor List	–	Data Element Sequence	–	C.1
Protocol #0	–	UUID	«L2CAP»	C.1
Parameter #0 for Protocol #0	PSM	Uint16	PSM = Enhanced ATT (EATT)	C.1
Protocol #1	–	UUID	«ATT»	C.1
BrowseGroupList	–	–	PublicBrowseRoot Other browse UUIDs may also be included in the list.	M

Table 4.1: SDP Record

C.1: Mandatory if Enhanced Attribute Protocol (EATT), introduced in Volume 3, Part F, Section 3.2.11 in [1], is supported, otherwise Excluded.

5 Acronyms and abbreviations

Acronym/Abbreviation	Meaning
AP	Antenna Path
ATT	Attribute Protocol
BR/EDR	Basic Rate/Enhanced Data Rate
CCC	Client Characteristic Configuration
CS	Channel Sounding
EATT	Enhanced ATT
FAE	Frequency Actuation Error
HCI	Host Controller Interface
L2CAP	Logical Link Control and Adaptation Protocol
LE	Low Energy
MTU	Maximum Transmission Unit
PCT	Phase Correction Term
PSM	Protocol/Service Multiplexer
RAS	Ranging Service
RAS-CP	RAS Control Point
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 5.4 or later

[2] GATT Specification Supplement

[3] Bluetooth Core Specification Supplement, Version 11

[4] High-Accuracy Distance Measurement FRD, Version r14

[5] Channel Sounding FIPD, Version r22

[6] Channel Sounding HCI Updates FIPD, Version r14