



THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

A VERIFIED OCPP v2.01 SERVER FOR ELECTRIC VEHICLE CHARGER NETWORKS

by
DANIEL HUGH MCINNES

School of Information Technology and Electrical Engineering,
The University of Queensland.

Submitted for the degree of
Master of Engineering
in the field of Software Engineering
June 2020.

Daniel McInnes
s4231125@student.uq.edu.au

June 12, 2020

Prof Amin Abbosh
Acting Head of School
School of Information Technology and Electrical Engineering
The University of Queensland
St Lucia, Q 4072

Dear Professor Abbosh,

In accordance with the requirements of the degree of Master of Engineering in the division of Software Engineering, I present the following thesis entitled “A Verified OCPP v2.01 Server for Electric Vehicle Charger Networks”. This work was performed under the supervision of A/Prof. Graeme Smith.

I declare that the work submitted in this thesis is my own, except as acknowledged in the text and footnotes, and has not been previously submitted for a degree at The University of Queensland or any other institution.

Yours sincerely,

Daniel McInnes.

Acknowledgments

I wish to acknowledge the support of my supervisor, Associate Professor Graeme Smith, whose expertise and assistance were greatly appreciated.

Abstract

Currently, networks of publicly available electric vehicle fast chargers communicate with servers using the Open Charge Point Protocol (OCPP). Ideally, the software running on these servers would be error free and never crash. Numerous software verification tools exist to prove desirable properties of the server software, such as functional correctness, the absence of race conditions, memory leaks, and certain runtime errors. The features of several verification tools were compared, and SPARK 2014 was chosen to partially implement an OCPP server.

A JavaScript program was developed to parse the JSON protocol definition and automatically generate SPARK code that converts raw text into OCPP packets, and vice versa. The generated code includes verification conditions to prove data dependencies, termination, and functional correctness.

The server was proven to be free of all runtime exceptions, excluding ‘out of memory’ exceptions.

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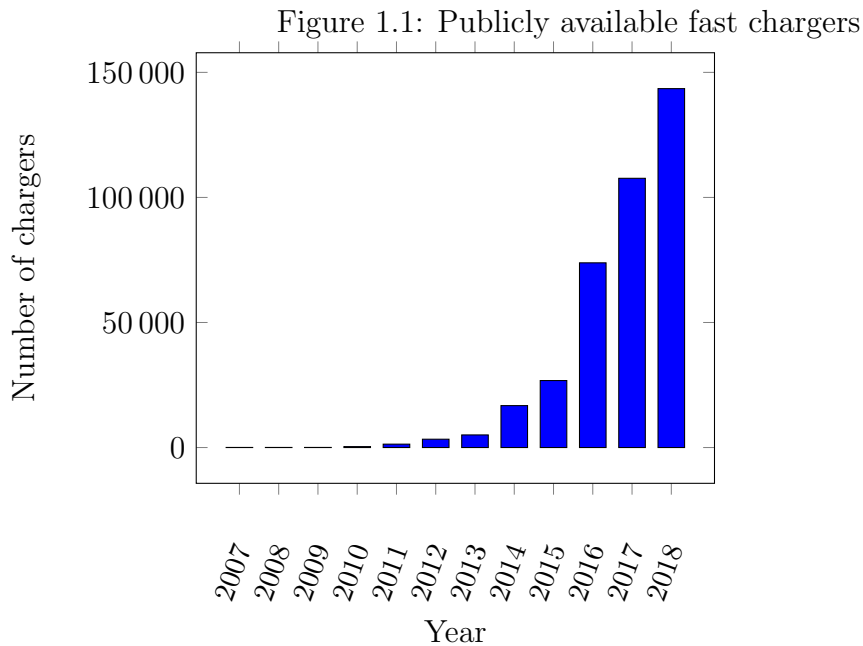
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Chapter 1

Introduction

The International Energy Agency [1] reports that the number of publicly available fast chargers ($> 22\text{kW}$) increased from 107 650 in 2017 to 143 502 in 2018.



The Open Charge Alliance [69] reports that more than 10 000 charging stations¹ in over 50 countries are managed using the OCPP protocol. A formally verified implementation of this protocol would be of great utility to charging infrastructure around the world.

In this paper the features of several different software verification tools are investigated and one chosen to partially implement an OCPP server. The tools include

¹Note that a “charging station” may consist of multiple fast chargers, thus the disparity between 143 502 “fast chargers” and “more than 10 000 charging stations”

Dafny, KeY, OpenJML, SPARK 2014, Spec#, VCC, VeriFast, Viper, Whiley, and Why3.

The tools vary in what guarantees they provide. Desirable guarantees include:

- the absence of memory leaks
- the program should never access uninitialized memory (for example, should never read past the end of an array)
- the program should never crash or exit unexpectedly
- the tool should verify the absence of stack overflows, i.e. the program should be bounded in terms of memory (RAM) usage at runtime
- the program should verifiably meet its requirements. These requirements are typically in the form of preconditions and postconditions.
- the program should never exhibit undefined behaviour
- the program should constrain information flow, i.e. not leak sensitive information such as passwords
- The tool should be sound. Many of the tools claim to be sound “modulo bugs in the tool”, and have lengthy lists of known bugs.

Chapter 2

Prior Art

Numerous software verification tools were considered for use in implementing the OCPP server. These tools include Dafny, KeY, OpenJML, SPARK 2014, Spec#, VCC, Verifast, Viper, Whiley, and Why3. SPARK 2014 was found to best fulfill the criteria [1](#).

2.1 Dafny

2.1.1 Home Page

<https://rise4fun.com/Dafny>

2.1.2 Features

Dafny is both a language and a verifier [\[62\]](#). Dafny supports feature verification via preconditions, postconditions, loop invariants and loop variants. It uses the ‘Boogie’ intermediate language and the Z3 theorem prover. The Dafny compiler produces executable files for the .NET platform [\[64\]](#).

2.1.3 Soundness

Dafny is designed to be sound but incomplete, and is known to report errors on correct programs [\[65\]](#).

2.1.4 Supported Platforms

Windows, Linux, OSX host, for a .NET target platform.

2.1.5 License Information

MIT.

2.1.6 Evidence of successful use in commercial software development

Internet searches failed to find any evidence of Dafny being used in commercial software development.

2.1.7 Existing Libraries

There is a ‘mathematics’ library for Dafny.

2.1.8 Multithreaded Application Support

Internet searches failed to find evidence of multithreaded application support.

2.1.9 Supported Languages

Dafny.

2.2 KeY

2.2.1 Home Page

<https://www.key-project.org/>

2.2.2 Features

KeY offers functional verification for Java programs. The specifications are written as comments in JML (Java Modelling Language [75]) in the Java source code. KeY is built on a formal logic called ‘Java Card DL’, which is itself a first-order dynamic logic, and an extension of Hoare logic. It is targeted at JavaCard programs.

2.2.3 Soundness

KeY is thought to be sound. Internet searches failed to find examples of unsoundness.

2.2.4 Supported Platforms

Windows, Linux, and OSX hosts, for a JVM target.

2.2.5 License Information

GPL.

2.2.6 Evidence of successful use in commercial software development

Internet searches failed to find any evidence of KeY being used in commercial software development.

2.2.7 Existing Libraries

There are extensive libraries available for Java programs.

2.2.8 Multithreaded Application Support

No.

2.2.9 Supported Languages

Java.

2.3 OpenJML

2.3.1 Home Page

<http://www.openjml.org/>

2.3.2 Features

OpenJML is a suite of tools for verifying Java programs that are annotated with JML statements. It is based on OpenJDKv1.8. It detects illegal memory access at compile time. It verifies preconditions and postconditions. It arguably guarantees the absence of undefined behaviour for single threaded applications. It does not constrain information flow.

2.3.3 Soundness

Yes

2.3.4 Supported Platforms

Windows, Linux, OSX.

2.3.5 License Information

GPLv2.

2.3.6 Evidence of successful use in commercial software development

Internet searches failed to find any evidence of OpenJML being used in commercial software development.

2.3.7 Existing Libraries

There are extensive libraries available for Java programs.

2.3.8 Multithreaded Application Support

No.

2.3.9 Supported Languages

Java (only OpenJDK v1.8, may become unsupported in December 2020)

2.4 SPARK 2014

SPARK 2014 is both a formally defined programming language and a set of verification tools. In typical use, a programmer writes SPARK code, which is compiled by the GNAT compiler, then analyzed by the GNATprove tool to produce numerous verification conditions. GNATprove uses Alt-Ergo, CVC4 and Z3 to prove the verification conditions.

Features

Formally verifies:

- information flow

- freedom from runtime errors, except ‘Storage_Error’ (stack overflow / heap exhaustion)
- functional correctness

Safety Standards

SPARK 2014 satisfies:

- DO-178B/C
- Formal Methods supplement DO-333
- CENELEC 51028
- IEC 61508
- DEFSTAN 00-56

Soundness

SPARK is thought to be sound. Internet searches failed to find examples of unsoundness.

Supported Platforms

Windows, Linux, OSX.

License Information

Dual license:

SPARK GPL is available for free from <http://libre.adacore.com> under the GPL.

SPARK PRO is available under a commercial license from <http://www.adacore.com>.

Evidence of successful use in commercial software development

There is abundant evidence of the successful use of SPARK in high integrity software development. See: [31], [28], [29], [2], [8], [23], [39], [5], [38], [17], [4], [10], [44], [25], [32], [37], [34], [22], [21], [19], [35], [36], [43], [24], [12], [33], [20], [14], [40], [26], [27], [42], [9], [46], [30], [7], [11], [47], [13], [6], [16], [15], [45], [18], [3].

Of particular relevance is the experience of the CubeSat Laboratory at Vermont Technical College[41]. Cubesats are small cubes launched into space with various sensors onboard, in this case without post-launch software update capabilities. This means the software must be fault free at the time of launch. The students (mostly third and fourth year undergraduates, with no prior knowledge of SPARK or Ada,

and a high turnover rate) proved the software to be free of runtime errors. 14 Cubesats were launched in November 2013. Most were never heard from again, but the SPARK Cubesat worked for 2 years until it reentered Earth’s atmosphere as planned in November 2015.

Existing Libraries

SPARK has a minimal container library. SPARK interfaces easily with Ada, which has an extensive standard library.

Multithreaded Application Support

Unsupported.

Supported Languages

SPARK 2104 supports a subset of Ada 2012.

See [63, p.18]

“The following Ada 2012 features are not currently supported by Spark:

Aliasing of names; no object may be referenced by multiple names

Goto statements

Expressions or functions with side effects

Exception handlers

Controlled types; types that provide fine control of object creation, assignment, and destruction

Tasking/multithreading (will be included in future releases)”

2.5 Spec#

2.5.1 Home Page

<https://www.microsoft.com/en-us/research/project/spec/>

2.5.2 Features

Spec# consists of the Spec# programming language, the Spec# compiler, and the Spec# static program verifier. The programming language is an extension of C#, adding non-null types, checked exceptions, preconditions, postconditions, and object invariants [66]. It uses Boogie for verification.

2.5.3 Soundness

Spec# claims to be sound[50].

2.5.4 Supported Platforms

Windows host platform, .NET target platform.

2.5.5 License Information

Internet searches failed to find Spec# license information.

2.5.6 Evidence of successful use in commercial software development

Internet searches failed to find evidence of Spec# being used in commercial software development.

2.5.7 Existing Libraries

Internet searches failed to find Spec# libraries. However, Spec# offers interoperability with the .NET platform, which has an extensive standard library, although the soundness of this library is not guaranteed.

2.5.8 Multithreaded Application Support

Yes[66].

2.5.9 Supported Languages

Spec#.

2.6 VCC

2.6.1 Home Page

<https://www.microsoft.com/en-us/research/project/vcc-a-verifier-for-concurrent-c/>

2.6.2 Features

VCC verifies preconditions and postconditions written in the form of special comments in the source code. It detects data races in multithreaded applications and illegal memory access at compile time. It does not guarantee the absence of undefined behaviour.

2.6.3 Soundness

Yes

2.6.4 Supported Platforms

Windows

2.6.5 License Information

MIT [\[68\]](#)

2.6.6 Evidence of successful use in commercial software development

VCC has been used successfully in at least one major commercial project, the verification of the Microsoft Hypervisor, the virtualization kernel of Hyper-V [\[53\]](#).

2.6.7 Existing Libraries

Internet searches failed to find libraries verified with VCC. However, applications written with VCC can link against unverified libraries, effectively giving access to extensive library support.

2.6.8 Multithreaded Application Support

Yes

2.6.9 Supported Languages

C

2.7 Verifast

2.7.1 Home Page

<https://github.com/verifast/verifast>

2.7.2 Features

Verifast verifies preconditions, and postconditions in the form of special comments in the source code. It detects race conditions in multithreaded applications. It does not guarantee the absence of undefined behaviour, or verify the absence of stack overflows.

2.7.3 Soundness

No, see <https://github.com/verifast/verifast/blob/master/soundness.md>

2.7.4 Supported Platforms

Windows, Linux, OSX.

2.7.5 License Information

MIT [61].

2.7.6 Evidence of successful use in commercial software development

There is evidence of some use in industrial applications[77].

2.7.7 Existing Libraries

Internet searches failed to find libraries verified by / written with VeriFast annotations. However, applications written with VeriFast can link against unverified libraries, effectively gaining access to extensive library support.

2.7.8 Multithreaded Application Support

Yes.

2.7.9 Supported Languages

C, Java

2.8 Viper

2.8.1 Home Page

<https://www.pm.inf.ethz.ch/research/viper.html>

2.8.2 Features

Viper consists of the Viper intermediate verification language, automatic verifiers, and example front end tools [57]. It is more of a tool for creating other verification tools than a tool for verifying software. In practice, a developer would write code in Python and use the ‘Nagini’ front end (based on Viper) to verify the code [55]. A corresponding front end for Rust exists, ‘Prusti’ [49].

2.8.3 Soundness

Yes.

2.8.4 Supported Platforms

Windows, MacOS, Linux[60].

2.8.5 License Information

<https://bitbucket.org/viperproject/carbon/src/default/LICENSE.txt> Mozilla Public License Version 2.0[56]

2.8.6 Evidence of successful use in commercial software development

Internet searches failed to find evidence of Viper being used in commercial software development.

2.8.7 Existing Libraries

Internet searches failed to find libraries verified by Viper front ends. However, applications written with these front ends can link against unverified libraries, effectively gaining access to extensive library support.

2.8.8 Multithreaded Application Support

Yes.

2.8.9 Supported Languages

Python, Rust, Java, OpenCL, Chalice.

2.9 Whiley

2.9.1 Home Page

<http://whiley.org/>

2.9.2 Features

Whiley consists of the Whiley language, the Whiley Build System, the Whiley Compiler, the Whiley Intermediate Language, the Whiley-2-Java Compiler, the Whiley-2-C Compiler, and the Whiley Constraint Solver[76].

Whiley uses a variant of first-order logic called the Whiley Assertion Language for verification.

In typical use, a developer will write source code in Whiley, build with the Whiley Build system, and execute the resulting Java class file on the JVM.

2.9.3 Soundness

Internet searches did not find evidence to indicate that Whiley is unsound.

2.9.4 Supported Platforms

JVM.

2.9.5 License Information

BSD.

2.9.6 Evidence of successful use in commercial software development

Internet searches failed to find evidence of Whiley being used in commercial software development.

2.9.7 Existing Libraries

Internet searches failed to find libraries verified by Whiley. However, applications written with Whiley can link against unverified Java functions, effectively gaining access to extensive library support.

2.9.8 Multithreaded Application Support

No.

2.9.9 Supported Languages

Whiley. The Whiley-2-Java Compiler (WyJC) can convert verified Whiley programs into JVM class files. Whiley can import Java functions, and export Whiley functions for use in Java programs.

2.10 Why3

2.10.1 Home Page

<http://why3.lri.fr/>

2.10.2 Features

The Why3 deductive program verification platform includes the WhyML language, a standard library of logical theories, and basic programming data structures[83]. In typical use, a developer will write software in WhyML, and get correct-by-construction OCaml programs through an automated extraction mechanism. It verifies preconditions and postconditions.

WhyML is also used by numerous popular verification tools (FramaC, SPARK2014, Krakatoa) as an intermediate language for verification of C, Java and Ada programs.

2.10.3 Soundness

Yes.

2.10.4 Supported Platforms

Windows, Linux, OSX. Why3 is distributed as a Debian package and as an OPAM package.

2.10.5 License Information

GNU LGPL 2.1.

2.10.6 Evidence of successful use in commercial software development

Internet searches failed to find evidence of WhyML being used in commercial software development. However, there are countless cases of commercial software development using WhyML as an intermediate language, as it is used by FramaC, SPARK, and others.

2.10.7 Existing Libraries

Why3 comes with a standard library of logical theories and basic programming data structures.

2.10.8 Multithreaded Application Support

No.

2.10.9 Supported Languages

WhyML.

2.11 Conclusion of Review of Background and Associated Work

Based on the properties of the verification tools available, it has been decided to use SPARK 2014 for the implementation and verification of the OCPP server. It has wide use in industry, which gives confidence that it is a practical choice. It verifies most of the properties desired, and has good library support.

Chapter 3

OCPP Server Implementation

3.1 OCPP Overview

An OCPP server acts as a websocket server. There are typically many individual charging stations, which act as websocket clients. The clients establish a websocket connection with the server, and once this is complete, JSON formatted packets are exchanged between the client and the server.

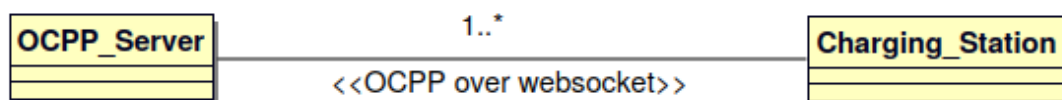


Figure 3.1: OCPP overview.

3.2 Minimal OCPP implementation

The OCPP protocol supports many use cases which are not required for a basic implementation. The following table [70] shows a minimal subset of OCPP messages required to support basic functionality.

Table 3.1: Use cases for a basic implementation

Functionality	Use Case	Messages
Booting a charge station	B01 - B04	BootNotification
Configuring a charge station	B05-B07	SetVariables, GetVariables, GetReportBase
Resetting a charge station	B11-B12	Reset
Authorization Options	One of C01, C02, C04	Authorize
Transaction Mechanism	E01 (one of S1-S6), E02-E03, E05, E06 (one of S1-S6), E07-E08, One of E09-E10, E11-E13	TransactionEvent
Availability	G01, G03-G04	ChangeAvailability, StatusNotification
Monitoring Events	G05, N07	NotifyEvent
Meter Values	J02	TransactionEvent
Data Transfer	P01-P02	DataTransfer

3.2.1 Boot Notification Discussion

To understand what interesting software properties may be proved, we will walk through a typical ‘BootNotification’ sequence.

Whenever a charger is powered on in the field, it establishes a websocket connection with the server, and sends a ‘BootNotificationRequest’ packet to announce itself. A high level view of a typical boot notification sequence is given in Figure 3.2.

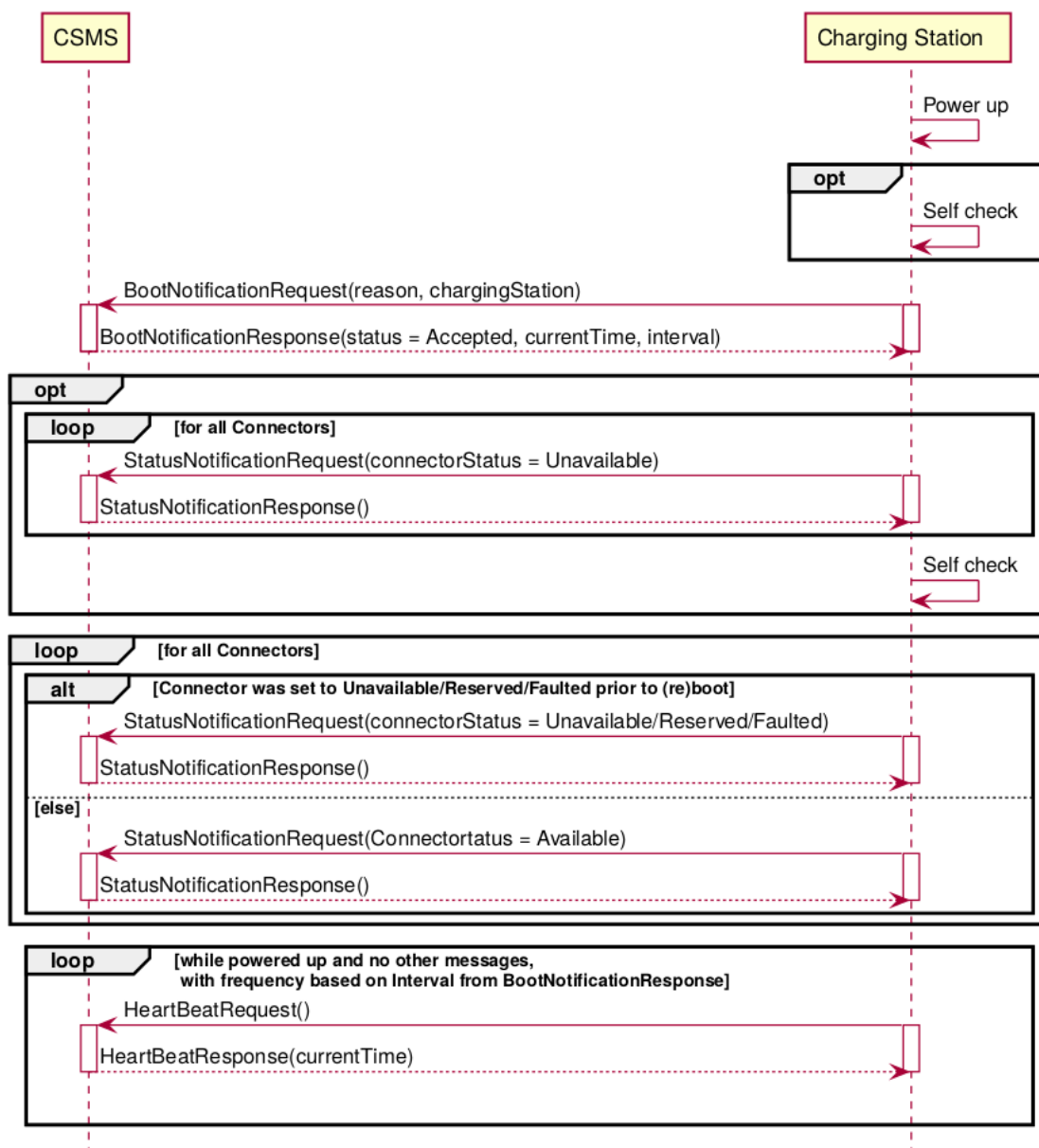


Figure 3.2: Cold Booting a Charging Station [73].

The ‘BootNotificationRequest’ packet contains information describing the charger. If the server recognises the charger, it returns a ‘BootNotificationResponse’ message with a status of ‘Accepted’. The contents of these packets is described in Figure 3.3.

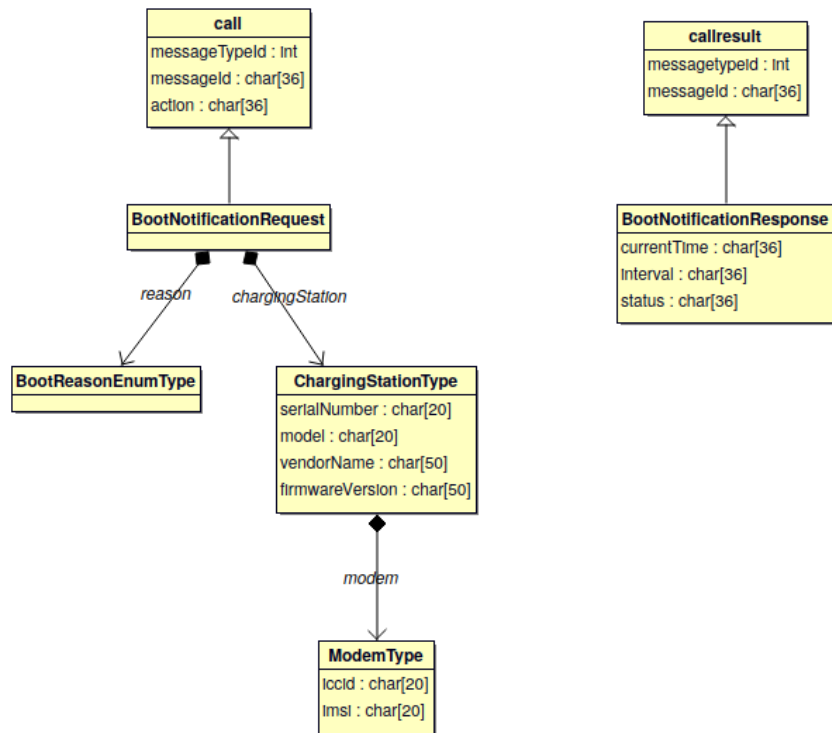


Figure 3.3: ‘Boot Notification’ class diagram

Note that figure 3.3 is a UML class diagram, the different arrow types have special meanings. The ‘BootNotificationRequest’ class inherits from the ‘call’ class, and has a member variable called ‘reason’ of class ‘BootReasonEnumType’. It also has a member variable called ‘chargingStation’ of class ‘ChargingStationType’, which in turn has a member variable called ‘modem’ of class ‘ModemType’.

The ‘BootNotificationRequest’ packet arrives at the server as JSON formatted text, as follows:

```
[2,          // '2' indicates that this is a 'request'
"19223202",// this is the message ID, and associates requests with responses
"BootNotification", // the 'action'
{
  "chargingStation":
  {
    "serialNumber": "0000000000000000000001",
    "model": "SingleSocketCharger",
    "modem":
    {
      "iccid": "01234567890123456789",
      "imsi": "01234567890123456789"
    },
    "vendorName": "VendorX",
    "firmwareVersion": "01.23456789"
  },
  "reason": "PowerUp"
}
]
```

The server’s job is to correctly parse this text, determine what kind of packet it is, and respond appropriately. In this example, the server converts the incoming JSON text into a ‘BootNotificationRequest’ packet, builds a ‘BootNotificationResponse’ packet, converts it to JSON formatted of text, and sends it back over the websocket to the charger. The response looks like this:

```
[3, // '3' indicates that this is a 'response'
"19223202", // this responds to request "19223202"
{
  "currentTime": "2013-02-01T20:53:32.486Z",
  "interval": 300,
  "status": "Accepted"
}
]
```

3.2.2 OCPP message types

Valid OCPP message types are either CALL, CALLRESULT, or CALLERROR.

CALL

A CALL consists of 4 parts, as described in Table 3.2

Field	Data Type	Meaning
MessageTypeId	Integer (=2)	This is a Message Type Number which is used to identify the type of the message.
MessageId	string[36]	This is a unique identifier that will be used to match request and result.
Action	string[36]	The name of the remote procedure or action. This field SHALL contain a case-sensitive string. The field SHALL contain the OCPP Message name without the "Request" suffix. For example: For a "BootNotificationRequest", this field shall be set to "BootNotification".
Payload	JSON	JSON Payload of the action.

Table 3.2: CALL message type [74]

CALLRESULT

A CALL consists of 4 parts, as described in Table 3.3

Field	Data Type	Meaning
MessageTypeId	Integer (=3)	This is a Message Type Number which is used to identify the type of the message.
MessageId	string[36]	This must be the exact same ID that is in the call request so that the recipient can match request and result.
Payload	JSON	JSON Payload of the action.

Table 3.3: CALLRESULT message type [74]

CALLERROR

The CALLERROR message is only used when an error occurs during message transport, or in response to an invalid OCPP message. A CALL consists of 5 parts, as described in Table 3.4.

Field	Data Type	Meaning
MessageTypeId	Integer (=4)	This is a Message Type Number which is used to identify the type of the message.
MessageId	string[36]	This must be the exact same ID that is in the call request so that the recipient can match request and result.
Action	string[36]	The name of the remote procedure or action. This field SHALL contain a case-sensitive string. The field SHALL contain the OCPP Message name without the "Request" suffix. For example: For a "BootNotificationRequest", this field shall be set to "BootNotification".
Payload	JSON	JSON Payload of the action.

Table 3.4: CALLERROR message type [74]

3.2.3 Implementation

The sequence diagram 3.4 describes the typical sequence of events that occurs when a charger is powered on, boots up and connects to a server. Prior to the charger booting, the charger is enrolled on the server. The server maintains a list of known chargers. Only chargers on this list may successfully start an OCPP session.

Once a charger powers up, it establishes a websocket connection with the server and communicates with OCPP packets over this link. The first OCPP message the charger sends is a 'BootNotificationRequest'.

When the server receives a message, it arrives in a function called 'ReceivePacket'.

3.2.4 ‘Server.ReceivePacket’ Function

The following code snippet contains the function prototype and verification conditions.

```

procedure ReceivePacket(theServer: in out ocpp.server.T;
                        msg: in NonSparkTypes.packet.Bounded_String;
                        response: out NonSparkTypes.packet.Bounded_String;
                        valid: out Boolean)

with
  Global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (
    valid => (msg),
    response => (msg, theServer),
    theServer => (msg, theServer)
  );

```

Global Data Dependencies

The line ‘*Global* \Rightarrow *null*’ specifies that the procedure may not modify any global variables.

‘Annotate’ section

By default, GNATprove does not prove termination of subprograms. The line ‘*Annotate* \Rightarrow (*GNATprove*, *Terminating*)’ specifies that the procedure must terminate, i.e. can never enter an endless loop.

‘Depends’ section

The ‘Depends’ clause means that:

- the final value of ‘valid’ depends only on ‘msg’. It makes sense that the validity of an OCPP packet depends only on the content of the message, and is independent of the state of the server.
- the final value of ‘response’ depends on ‘msg’ and on ‘theServer’. It makes intuitive sense that the response depends on what the request was. It may not be immediately obvious why the response should depend on the state of the server, until we consider that the server maintains a list of known chargers, and will respond to BootNotificationRequests with a ‘Rejected’ status for unknown chargers.

- the final value of ‘theServer’ depends on the initial state of ‘theServer’ and on ‘msg’.

GNATprove reports an error if any of these specifications are not met by the implementation.

The first thing the function ‘ReceivePacket’ does is parse the ‘MessageType’, as seen in Figure 3.4.

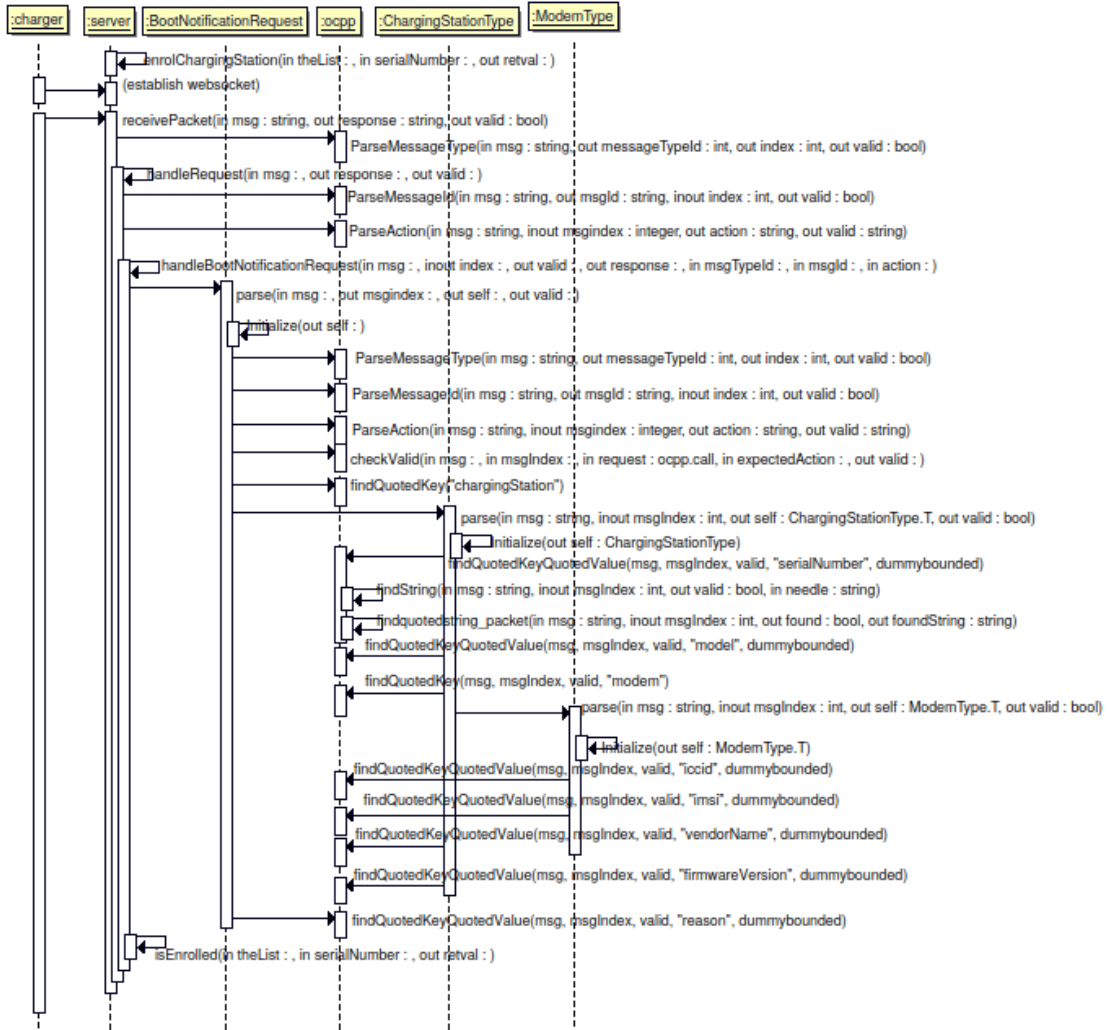


Figure 3.4: Cold Booting a Charging Station [73].

3.2.5 ‘OCPP.ParseMessageType’ Function

```

procedure ParseMessageType(msg:   in  NonSparkTypes.packet.Bounded_String;
                             msgtypeid : out integer;-- eg. 2
                             index: in out Integer;
                             valid: out Boolean)

with  Global => null,
Annotate => (GNATprove, Terminating),
Post => (if valid = true then
        (msgtypeid = 2 or msgtypeid = 3 or msgtypeid = 4)
        and
        (index < NonSparkTypes.packet.Length(msg))
        );

```

‘Post’ section

The ‘Post’ clause means that:

- if the function returns ‘valid = true’, then the ‘msgtypeid’ must be one of the valid OCPP message types, i.e. 2, 3 or 4.
- if the function returns ‘valid = true’, then the ‘index’ must not have moved past the end of ‘msg’. This postcondition is included as a sanity check.

GNATprove reports an error if any of these specifications are not met by the implementation.

Once we have successfully parsed the message type, we know whether it is a ‘request’ or a ‘response’. In this example, the server has received a ‘BootNotificationRequest’, so we pass the message to ‘HandleRequest’ for further parsing.

3.2.6 ‘Server.HandleRequest’ Function

```

procedure HandleRequest(theServer: in ocpp.server.T;
                       msg: in NonSparkTypes.packet.Bounded_String;
                       msgindex: in out Integer;
                       response: out NonSparkTypes.packet.Bounded_String;
                       valid: out Boolean)

with
  global => null,
  Annotate => (GNATprove, Terminating),

```

```

Depends => (
    valid => (msg, msgindex),
    msgindex => (msg, msgindex),
    response => (msg, msgindex, theServer)
),
Post => (if valid = true then msgindex <= NonSparkTypes.packet.Length(msg));

```

‘Depends’ section

- The final value of ‘valid’ depends only on ‘msg’ and ‘msgindex’. The reason ‘valid’ depends on ‘msgindex’ is that if the index was already pointing at the end of the message, there would not be enough information left to construct a valid request.
- The final value of ‘msgindex’ depends only on ‘msg’ and ‘msgindex’. This makes sense, as if the message was invalid, the function will return early, without parsing much of the message, thus affecting the final value of ‘index’. The reason the final value of ‘msgindex’ depends on the initial value of ‘msgindex’ is that if the index was already pointing at the end of the message, the function would return without advancing ‘msgindex’ through the message.
- The value of ‘response’ depends on ‘msg’, ‘msgindex’ and ‘theServer’.

‘Post’ section

The ‘Post’ clause means that:

- if the function returns ‘valid = true’, then the ‘index’ must not have moved past the end of ‘msg’. This postcondition is included as a sanity check.

GNATprove reports an error if any of these specifications are not met by the implementation.

The body of ‘HandleRequest()’ calls ‘ParseAction’ to determine what kind of request it is.

3.2.7 ‘OCPP.ParseAction’ Function

```

procedure ParseAction(msg:   in  NonSparkTypes.packet.Bounded_String;
                        msgindex: in out Integer;
                        action : out NonSparkTypes.action_t.Bounded_String;
                        valid: out Boolean

```



```

    )
  with Global => null,
  Annotate => (GNATprove, Terminating),
  Post => (if valid = true
    then
      (msgindex < NonSparkTypes.packet.Length(msg))
    );

```

‘Post’ section

The ‘Post’ clause means that:

- if the function returns ‘valid = true’, then the ‘index’ must not have moved past the end of ‘msg’. This postcondition is included as a sanity check.

GNATprove reports an error if any of these specifications are not met by the implementation.

In this case, the action is ‘BootNotification’, so ‘HandleRequest’ calls ‘HandleBootNotificationRequest’.

3.2.8 ‘Server.HandleBootNotificationRequest’ Function

```

procedure HandleBootNotificationRequest(
  theServer: in ocpp.server.T;
  msg: in NonSparkTypes.packet.Bounded_String;
  index : out Integer;
  valid: out Boolean;
  response: out NonSparkTypes.packet.Bounded_String)
with
  global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (
    index => (msg),
    valid => (msg),
    response => (msg, theServer)
  );

```

The first thing this function does is call ‘BootNotificationRequest.parse’.

3.2.9 ‘BootNotificationRequest.parse’ Function

```

procedure parse(msg: in NonSparkTypes.packet.Bounded_String;
               msgindex: out Integer;
               self: out ocpp.BootNotificationRequest.T;
               valid: out Boolean
            )
with
  Global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (
    valid => (msg),
    msgindex => (msg),
    self => (msg)
  ),
  post => (if valid = true then
    (self.messageid = 2) and
    (NonSparkTypes.messageid_t.Length(self.messageid) > 0) and
    (self.action = action) -- prove that the original packet contains the
  );

```

The first thing this function does is call ‘Initialise’, which sets all member variables to a known state.

3.2.10 ‘BootNotificationRequest.Initialize’ Function

```

procedure Initialize(self: out ocpp.BootNotificationRequest.T)
with
  Global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (self => null);

```

This function always sets member variables to the same values, and returns to ‘BootNotificationRequest.parse()’.

Next, `ocpp.ParseMessageId()` is called.

3.2.11 ‘ocpp.ParseMessageId’ Function

```

procedure ParseMessageId(msg: in NonSparkTypes.packet.Bounded_String;

```

```

        messageid : out NonSparkTypes.messageid_t.Bounded_Str
        index: in out Integer;
        valid: out Boolean
    )      with
    global => null,
    Annotate => (GNATprove, Terminating);

```

This function parses the ‘messageId’, which is used to match ocpp requests with ocpp responses. It stores the result in a member variable, and returns to ‘BootNotificationRequest.parse()’, which then calls additional utility parsing functions until all of the ‘BootNotificationRequest’ member variables have been populated with the corresponding values from the incoming message. The function then returns to ‘server.HandleBootNotificationRequest()’, which calls ‘server.IsEnrolled()’.

3.2.12 ‘Server.IsEnrolled’ Function

```

procedure IsEnrolled(theList: in ChargerList.vecChargers_t;
                    serialNumber: in NonSparkTypes.ChargingStationType.strserial;
                    retval: out Boolean)
with
    global => null,
    Annotate => (GNATprove, Terminating),
    Depends => (
        retval => (serialNumber, theList)
    );

```

If the list contains the supplied serial number, it returns true, otherwise false. In this case, the serial number is in the list, so we respond to the BootNotificationRequest with a BootNotificationResponse with a status of ‘accepted’. This response packet is serialized into text, which is then sent to the charger. The server’s job is complete, it has received a valid request, parsed it, created an appropriate response, and sent it back to the client.

The basic sequence of events is similar for all OCPP packets.

3.3 Automated Code Generation

The OCPP protocol defines 128 different messages. Some of these packets are deeply nested JSON structures, with lists of elements each containing further lists of elements. It was realised early in the project that the time required to manually implement serializing and deserializing (converting from raw text to a binary representation, and converting from the binary representation back to raw text) for each of these packets would be prohibitive. The protocol documentation includes the corresponding JSON definitions of all of these packets, each with their own ‘.json’ file (eg. ‘BootNotificationRequest.json’, ‘BootNotificationResponse.json’).

A JavaScript program called ‘parse.js’ was written to parse each of these ‘.json’ files, and generate the corresponding SPARK implementation and definition files (eg. ‘BootNotificationRequest.ads’, ‘BootNotificationRequest.adb’, ‘BootNotificationResponse.ads’, ‘BootNotificationResponse.adb’). ‘BootNotificationRequest.json’ (see complete file in Appendix B) is examined here in detail.

3.3.1 Automatically parsing BootNotificationRequest.json

The parsing script starts with the ‘definitions’ section, which contains additional definitions for ‘CustomDataType’, ‘BootReasonEnumType’, ‘ChargingStationType’ (which itself contains further subtype definitions), and ‘ModemType’.

CustomDataType

This curious addition to the packet definition defines an optional extra string for extending the protocol functionality. All of the packet JSON definitions have this field, but it is not referenced anywhere else in the protocol specification. It is ignored in this OCPP implementation.

BootReasonEnumType

The following JSON snippet contains the definition for an enumerated type.

```
{
  "BootReasonEnumType": {
    "description": "This contains the reason for sending this
      message to the CSMS.\r\n",
    "javaType": "BootReasonEnum",
    "type": "string",
    "additionalProperties": false,
    "enum": [
      "ApplicationReset",
```

```

        "FirmwareUpdate",
        "LocalReset",
        "PowerUp",
        "RemoteReset",
        "ScheduledReset",
        "Triggered",
        "Unknown",
        "Watchdog"
    ]
}

```

‘parse.js’ generates the following SPARK implementation and definition files to serialise and deserialise this enum.

BootReasonEnumType.ads

The server needs to be able to serialize and deserialize ‘BootReasonEnumType’.

```
{
```

– Note: an ‘.ads’ file is the moral equivalent of a ‘.h’ file in C/C++

```
-- start ocppBootReasonEnumType.ads
```

– Note: The following is the same as a ‘#include’ statement in C/C++

```
with Ada.Strings.Bounded;
```

– Note: The following is the same as an ‘enum’ type definition in C/C++

```
package ocpp.BootReasonEnumType is
```

```

    type T is (
        ApplicationReset,
        FirmwareUpdate,
        LocalReset,
        PowerUp,
        RemoteReset,
        ScheduledReset,
        Triggered,
        Unknown,
        Watchdog
    );

```

- Note: The following defines a new string type with a maximum length of 16 characters

```
package string_t is new
  Ada.Strings.Bounded.Generic_Bounded_Length(Max => 16);
```

- Note: The following defines a new procedure to serialize raw text into a `BootReasonEnumType` object.

```
procedure FromString(str : in String;
                    attribute : out T;
                    valid : out Boolean)

with
  Global => null,
  Annotate => (GNATprove, Terminating);
```

- Note: The following defines a new procedure to deserialize a `BootReasonEnumType` object into raw text.

```
procedure ToString(attribute : in T;
                  str : out string_t.Bounded_String)

with
  Global => null,
  Annotate => (GNATprove, Terminating);
end ocpp.BootReasonEnumType;
-- end ocpp-BootReasonEnumType.ads
```

BootReasonEnumType.adb

```
{
```

- Note: An ‘.adb’ file is the moral equivalent of a ‘.c’ in C, or a ‘.cpp’ file in C++.

```
-- ocpp-BootReasonEnumType.adb
```

```
with ocpp.BootReasonEnumType; use ocpp.BootReasonEnumType;
```

- Note: ‘NonSparkTypes’ contains features that are needed that aren’t proven by SPARK. For example, printing debug text to standard out cannot be proven to terminate.

```
with NonSparkTypes;
```

```
package body ocpp.BootReasonEnumType is
```

– Note: The following is the implementation of the ‘FromString’ function.

```

procedure FromString(str : in String;
                    attribute : out T;
                    valid : out Boolean)
is
begin
  if (NonSparkTypes.Uncased_Equals(str, "ApplicationReset")) then
    attribute := ApplicationReset;
  elsif (NonSparkTypes.Uncased_Equals(str, "FirmwareUpdate")) then
    attribute := FirmwareUpdate;
  elsif (NonSparkTypes.Uncased_Equals(str, "LocalReset")) then
    attribute := LocalReset;
  elsif (NonSparkTypes.Uncased_Equals(str, "PowerUp")) then
    attribute := PowerUp;
  elsif (NonSparkTypes.Uncased_Equals(str, "RemoteReset")) then
    attribute := RemoteReset;
  elsif (NonSparkTypes.Uncased_Equals(str, "ScheduledReset")) then
    attribute := ScheduledReset;
  elsif (NonSparkTypes.Uncased_Equals(str, "Triggered")) then
    attribute := Triggered;
  elsif (NonSparkTypes.Uncased_Equals(str, "Unknown")) then
    attribute := Unknown;
  elsif (NonSparkTypes.Uncased_Equals(str, "Watchdog")) then
    attribute := Watchdog;
  else
    valid := false;
    return;
  end if;
  valid := true;
end FromString;

procedure ToString(attribute : in T;
                  str : out string_t.Bounded_String)
is
  use string_t;
begin
  case attribute is
    when ApplicationReset =>
      str := To_Bounded_String("ApplicationReset");

```

```

when FirmwareUpdate
  => str := To_Bounded_String("FirmwareUpdate");
when LocalReset
  => str := To_Bounded_String("LocalReset");
when PowerUp
  => str := To_Bounded_String("PowerUp");
when RemoteReset
  => str := To_Bounded_String("RemoteReset");
when ScheduledReset
  => str := To_Bounded_String("ScheduledReset");
when Triggered
  => str := To_Bounded_String("Triggered");
when Unknown
  => str := To_Bounded_String("Unknown");
when Watchdog
  => str := To_Bounded_String("Watchdog");
end case;
end ToString;
end ocpp.BootReasonEnumType;

```

Note that the specification includes several verification conditions, specifying that the ‘FromString’ and ‘ToString’ procedures may not modify global state and must terminate.

ChargingStationType

The following JSON snippet contains the definition for a more complex type, with properties defined by references to other types.

```

{
  "ChargingStationType": {
    "description": "Charge_ Point\r\nurn:x-oca:ocpp:uid:2:233122\r\nThe physical system where an Electrical Vehicle (EV) can be charged.\r\n",
    "javaType": "ChargingStation",
    "type": "object",
    "additionalProperties": false,
    "properties": {
      "customData": {
        "$ref": "#/definitions/CustomDataType"
      },
    },
  },

```



```

    "serialNumber": {
      "description": "Device. Serial_ Number. Serial_ Number\r\nurn:x-oca:ocpp:uid:1:569324\r\nVendor-specific device identifier.\r\n",
      "type": "string",
      "maxLength": 25
    },
    "model": {
      "description": "Device. Model. CI20_ Text\r\nurn:x-oca:ocpp:uid:1:569325\r\nDefines the model of the device.\r\n",
      "type": "string",
      "maxLength": 20
    },
    "modem": {
      "$ref": "#/definitions/ModemType"
    },
    "vendorName": {
      "description": "Identifies the vendor (not necessarily in a unique manner).\r\n",
      "type": "string",
      "maxLength": 50
    },
    "firmwareVersion": {
      "description": "This contains the firmware version of the Charging Station.\r\n\r\n",
      "type": "string",
      "maxLength": 50
    }
  },
  "required": [
    "model",
    "vendorName"
  ]
}

```

‘parse.js’ generates the following SPARK implementation and definition files to serialise and deserialise this type.

ChargingStationType.ads

```
{
```

```
pragma SPARK_mode (on);
```

```
with Ada.Strings.Fixed; use Ada.Strings.Fixed;
with NonSparkTypes; use NonSparkTypes.action_t;
with ocpp; use ocpp;
with ocpp.ModemType; use ocpp.ModemType;
```

```
package ocpp.ChargingStationType is
```

– Note: The ‘record’ keyword is similar to a ‘struct’ in C/C++.

```
type T is record
  zzzArrayElementInitialized : Boolean := False;
  serialNumber :
    NonSparkTypes.ChargingStationType.strserialNumber_t.Bounded_String;
  model : NonSparkTypes.ChargingStationType.strmodel_t.Bounded_String;
  modem : ModemType.T;
  vendorName :
    NonSparkTypes.ChargingStationType.strvendorName_t.Bounded_String;
  firmwareVersion :
    NonSparkTypes.ChargingStationType.strfirmwareVersion_t.Bounded_String;
end record;
procedure Initialize(self: out ocpp.ChargingStationType.T)
with
  Global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (self => null);

procedure parse(msg: in NonSparkTypes.packet.Bounded_String;
  msgindex: in out Integer;
  self: out ocpp.ChargingStationType.T;
  valid: out Boolean
)
with
  Global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (
    valid => (msg, msgindex),
    msgindex => (msg, msgindex),
```

```

        self => (msg, msgindex)
    );

    procedure To_Bounded_String(Self: in T;
                                retval: out NonSparkTypes.packet.Bounded_String)
        with
        Global => null,
        Annotate => (GNATprove, Terminating);
end ocpp.ChargingStationType;

```

ChargingStationType.adb

```

pragma SPARK_mode (on);

with ocpp;
with ocpp.ChargingStationType;
with Ada.Strings; use Ada.Strings;

package body ocpp.ChargingStationType is

```

Note: The following function refines a ‘generic’ function, with specialized types for ‘Max’, ‘string_t’, and specialized functions for ‘length()’, ‘To_String()’, and ‘To_Bounded_String()’.

```

procedure findquotedstring_packet is new findquotedstring(
    Max => NonSparkTypes.packet.Max_Length,
    string_t => NonSparkTypes.packet.Bounded_String,
    length => NonSparkTypes.packet.Length,
    To_String => NonSparkTypes.packet.to_string,
    To_Bounded_String => NonSparkTypes.packet.To_Bounded_String);

```

Note: The following function is required in order to ensure all data is initialized before it is used.

```

procedure Initialize(self: out ocpp.ChargingStationType.T)
is
begin
    NonSparkTypes.put_line("Initialize()");
    self.zzzArrayElementInitialized := False;
    self.serialNumber :=
        NonSparkTypes.ChargingStationType.strserialNumber_t.To_Bounded_String("");

```

```

self.model :=
  NonSparkTypes.ChargingStationType.strmodel_t.To_Bounded_String("");
ModemType.Initialize(self.modem);
self.vendorName :=
  NonSparkTypes.ChargingStationType.strvendorName_t.To_Bounded_String("");
self.firmwareVersion :=
  NonSparkTypes.ChargingStationType.strfirmwareVersion_t.To_Bounded_String("");
end Initialize;

procedure parse(msg:   in  NonSparkTypes.packet.Bounded_String;
                msgindex: in out Integer;
                self: out  ocpp.ChargingStationType.T;
                valid: out Boolean)
is
  dummybounded:
    NonSparkTypes.packet.Bounded_String :=
      NonSparkTypes.packet.To_Bounded_String("");
  dummyInt: integer;
begin
  Initialize(self);
  ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid, "serialNumber",
    dummybounded);
  if (valid = false)
  then
    NonSparkTypes.put_line("333 Invalid ChargingStationTypeserialNumber");
    return;
  end if;

  self.serialNumber :=
    NonSparkTypes.ChargingStationType.strserialNumber_t.To_Bounded_String(
      NonSparkTypes.packet.To_String(dummybounded), Drop => Right);

  ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid, "model", dummybounded);
  if (valid = false)
  then
    NonSparkTypes.put_line("333 Invalid ChargingStationTypemodel");
    return;
  end if;

```

```

self.model :=
  NonSparkTypes.ChargingStationType.strmodel_t.To_Bounded_String(
    NonSparkTypes.packet.To_String(dummybounded), Drop => Right);

ocpp.findQuotedKey(msg, msgIndex, valid, "modem");
if (valid = false)
then
  NonSparkTypes.put_line("355 Invalid ChargingStationTypemodem");
  return;
end if;

ModemType.parse(msg, msgindex, self.modem, valid);
if (valid = false)
then
  NonSparkTypes.put_line("357 Invalid ChargingStationTypemodem");
  return;
end if;

ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid, "vendorName",
  dummybounded);

if (valid = false)
then
  NonSparkTypes.put_line("333 Invalid ChargingStationTypevendorName");
  return;
end if;

self.vendorName :=
  NonSparkTypes.ChargingStationType.strvendorName_t.To_Bounded_String(
    NonSparkTypes.packet.To_String(dummybounded), Drop => Right);

ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid,
  "firmwareVersion", dummybounded);

if (valid = false)
then
  NonSparkTypes.put_line("333 Invalid ChargingStationTypefirmwareVersion");
  return;
end if;

```

```

self.firmwareVersion :=
  NonSparkTypes.ChargingStationType.strfirmwareVersion_t.To_Bounded_String(
    NonSparkTypes.packet.To_String(dummybounded), Drop => Right);

if (valid = false)
then
  NonSparkTypes.put_line("365 Invalid ChargingStationTypefirmwareVersion");
  return;
end if;

valid := true;
end parse;

procedure To_Bounded_String(Self: in T;
                           retval: out NonSparkTypes.packet.Bounded_String)
is
  dummybounded: NonSparkTypes.packet.Bounded_String :=
    NonSparkTypes.packet.To_Bounded_String("");
  strmodem : NonSparkTypes.packet.Bounded_String;
begin
  ModemType.To_Bounded_String(Self.modem, strmodem);
  retval := NonSparkTypes.packet.To_Bounded_String("
    & "{" & ASCII.LF
    & "      " & ''' & "serialNumber" & ''' & ": " & ''' &
    NonSparkTypes.ChargingStationType.strserialNumber_t.To_String(
      Self.serialNumber) &
    ''' & "," & ASCII.LF
    & "      " & ''' & "model" & ''' & ": " & ''' &
    NonSparkTypes.ChargingStationType.strmodel_t.To_String(Self.model) &
    ''' & "," & ASCII.LF
    & "      " & ''' & "modem" & ''' & ": " &
    NonSparkTypes.packet.To_String(strmodem) & "," & ASCII.LF
    & "      " & ''' & "vendorName" & ''' & ": " & ''' &
    NonSparkTypes.ChargingStationType.strvendorName_t.To_String(
      Self.vendorName) &
    ''' & "," & ASCII.LF
    & "      " & ''' & "firmwareVersion" & ''' & ": " & ''' &
    NonSparkTypes.ChargingStationType.strfirmwareVersion_t.To_String(

```

```

        Self.firmwareVersion) &
        ''' & ASCII.LF
        & "}" & ASCII.LF, Drop => Right);
    end To_Bounded_String;
end ocpp.ChargingStationType;

```

Note that the specification for ‘ChargingStationType’ depends on ‘ModemType’, which is defined in another file. The code generation script automatically adds the statement ‘with ocpp.ModemType; use ocpp.ModemType;’ to the specification file, to allow compilation to succeed. Verification conditions are automatically added to prove termination, absence of access to global data, and data flow dependencies.

ModemType

The following JSON snippet contains the definition for ‘ModemType’, which is used by the ‘BootNotificationRequest’ packet.

```

"ModemType": {
  "description": "Wireless_ Communication_ Module\r\n
urn:x-oca:ocpp:uid:2:233306\r\n
Defines parameters required for initiating and maintaining
wireless communication with other devices.\r\n",
  "javaType": "Modem",
  "type": "object",
  "additionalProperties": false,
  "properties": {
    "customData": {
      "$ref": "#/definitions/CustomDataType"
    },
    "iccid": {
      "description": "Wireless_ Communication_ Module. ICCID. CI20_
Text\r\nurn:x-oca:ocpp:uid:1:569327\r\nThis contains the ICCID
of the modem's SIM card.\r\n",
      "type": "string",
      "maxLength": 20
    },
    "imsi": {
      "description": "Wireless_ Communication_ Module. IMSI. CI20_
Text\r\nurn:x-oca:ocpp:uid:1:569328\r\nThis contains the IMSI
of the modem's SIM card.\r\n",
      "type": "string",

```

```

        "maxLength": 20
    }
}
}
}

```

‘parse.js’ generates the following SPARK implementation and definition files to serialise and deserialise this type.

ModemType.ads

```

pragma SPARK_mode (on);

with Ada.Strings.Fixed; use Ada.Strings.Fixed;
with NonSparkTypes; use NonSparkTypes.action_t;
with ocpp; use ocpp;

package ocpp.ModemType is
  type T is record
    zzzArrayElementInitialized : Boolean := False;
    iccid : NonSparkTypes.ModemType.striccid_t.Bounded_String;
    imsi : NonSparkTypes.ModemType.strimsi_t.Bounded_String;
  end record;
  procedure Initialize(self: out ocpp.ModemType.T)
  with
    Global => null,
    Annotate => (GNATprove, Terminating),
    Depends => (self => null);

  procedure parse(msg: in NonSparkTypes.packet.Bounded_String;
    msgindex: in out Integer;
    self: out ocpp.ModemType.T;
    valid: out Boolean
  )
  with
    Global => null,
    Annotate => (GNATprove, Terminating),
    Depends => (
      valid => (msg, msgindex),
      msgindex => (msg, msgindex),

```



```

        self => (msg, msgindex)
    );

    procedure To_Bounded_String(Self: in T;
                                retval: out NonSparkTypes.packet.Bounded_String)
        with
        Global => null,
        Annotate => (GNATprove, Terminating);
end ocpp.ModemType;

```

ModemType.adb

```

pragma SPARK_mode (on);

with ocpp;
with ocpp.ModemType;
with Ada.Strings; use Ada.Strings;

package body ocpp.ModemType is

    procedure findquotedstring_packet is new findquotedstring(
        Max => NonSparkTypes.packet.Max_Length,
        string_t => NonSparkTypes.packet.Bounded_String,
        length => NonSparkTypes.packet.Length,
        To_String => NonSparkTypes.packet.to_string,
        To_Bounded_String => NonSparkTypes.packet.To_Bounded_String);

    procedure Initialize(self: out ocpp.ModemType.T)
    is
    begin
        NonSparkTypes.put_line("Initialize()");
        self.zzzArrayElementInitialized := False;
        self.iccid := NonSparkTypes.ModemType.striccid_t.To_Bounded_String("");
        self.imsi := NonSparkTypes.ModemType.strimsi_t.To_Bounded_String("");
    end Initialize;

    procedure parse(msg: in NonSparkTypes.packet.Bounded_String;
                    msgindex: in out Integer;
                    self: out ocpp.ModemType.T;

```

```

        valid: out Boolean
    )

is
    dummybounded: NonSparkTypes.packet.Bounded_String :=
        NonSparkTypes.packet.To_Bounded_String("");
    dummyInt: integer;
begin
    Initialize(self);
    ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid, "iccid",
        dummybounded);
    if (valid = false)
    then
        NonSparkTypes.put_line("333 Invalid ModemTypeiccid");
        return;
    end if;

    self.iccid :=
        NonSparkTypes.ModemType.striccid_t.To_Bounded_String(
            NonSparkTypes.packet.To_String(dummybounded), Drop => Right);

    ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid, "imsi",
        dummybounded);
    if (valid = false)
    then
        NonSparkTypes.put_line("333 Invalid ModemTypeeimsi");
        return;
    end if;

    self.imsi := NonSparkTypes.ModemType.strimsi_t.To_Bounded_String(
        NonSparkTypes.packet.To_String(dummybounded), Drop => Right);

    if (valid = false)
    then
        NonSparkTypes.put_line("365 Invalid ModemTypeeimsi");
        return;
    end if;
    valid := true;
end parse;

```

```

procedure To_Bounded_String(Self: in T;
                           retval: out NonSparkTypes.packet.Bounded_String)
is
    dummybounded: NonSparkTypes.packet.Bounded_String :=
        NonSparkTypes.packet.To_Bounded_String("");
begin
    retval := NonSparkTypes.packet.To_Bounded_String("
        & "{" & ASCII.LF
        & "    " & "'" & "iccid" & "'" & ": " & "'" &
        NonSparkTypes.ModemType.striccid_t.To_String(Self.iccid) &
        "'" & "," & ASCII.LF &
        "    " & "'" & "imsi" & "'" & ": " & "'" &
        NonSparkTypes.ModemType.strimsi_t.To_String(Self.imsi) & "'"
        & ASCII.LF & "}" & ASCII.LF, Drop => Right);
end To_Bounded_String;
end ocpp.ModemType;

```

BootNotificationRequest

The following JSON snippet contains the definition for ‘BootNotificationRequest’, which depends on the previously defined types ‘ChargingStationType’ and ‘BootReasonEnumType’.

```

"type": "object",
"additionalProperties": false,
"properties": {
    "customData": {
        "$ref": "#/definitions/CustomDataType"
    },
    "chargingStation": {
        "$ref": "#/definitions/ChargingStationType"
    },
    "reason": {
        "$ref": "#/definitions/BootReasonEnumType"
    }
},
"required": [
    "reason",
    "chargingStation"
]

```

]

‘parse.js’ generates the following SPARK implementation and definition files to serialise and deserialise this type.

BootNotificationRequest.ads

```
pragma SPARK_mode (on);

with Ada.Strings.Fixed; use Ada.Strings.Fixed;
with NonSparkTypes; use NonSparkTypes.action_t;
with ocpp; use ocpp;
with ocpp.ChargingStationType; use ocpp.ChargingStationType;
with ocpp.BootReasonEnumType; use ocpp.BootReasonEnumType;

package ocpp.BootNotificationRequest is
  action : constant NonSparkTypes.action_t.Bounded_String :=
    NonSparkTypes.action_t.To_Bounded_String("BootNotification");
```

– Note that the following declaration of type ‘T’ is an example of inheritance. ‘BootNotificationRequest.T’ inherits from the type ‘call’, and adds two member variables, ‘chargingStation’ and ‘reason’.

```
type T is new call with record
  chargingStation : ChargingStationType.T;
  reason : BootReasonEnumType.T;
end record;
procedure Initialize(self: out ocpp.BootNotificationRequest.T)
with
  Global => null,
  Annotate => (GNATprove, Terminating),
  Depends => (self => null);

procedure parse(msg: in NonSparkTypes.packet.Bounded_String;
  msgindex: out Integer;
  self: out ocpp.BootNotificationRequest.T;
  valid: out Boolean
)

with
  Global => null,
  Annotate => (GNATprove, Terminating),
```

```

    Depends => (
        valid => (msg),
        msgindex => (msg),
        self  => (msg)
    ),
    post => (if valid = true then
        (self.messagetypeid = 2) and
        (NonSparkTypes.messageid_t.Length(self.messageid) > 0) and
        (self.action = action) -- prove that the original packet
        -- contains the corresponding "action"
    );

    procedure To_Bounded_String(Self: in T;
                                retval: out NonSparkTypes.packet.Bounded_String)
        with
        Global => null,
        Annotate => (GNATprove, Terminating);
end ocpp.BootNotificationRequest;

```

BootNotificationRequest.adb

```

pragma SPARK_mode (on);

with ocpp;
with ocpp.BootNotificationRequest;
with Ada.Strings; use Ada.Strings;

package body ocpp.BootNotificationRequest is

    procedure findquotedstring_packet is new findquotedstring(
        Max => NonSparkTypes.packet.Max_Length,
        string_t => NonSparkTypes.packet.Bounded_String,
        length => NonSparkTypes.packet.Length,
        To_String => NonSparkTypes.packet.to_string,
        To_Bounded_String => NonSparkTypes.packet.To_Bounded_String);

    procedure Initialize(self: out ocpp.BootNotificationRequest.T)
    is
    begin
        NonSparkTypes.put_line("Initialize()");
    end Initialize;
end BootNotificationRequest;

```

```

self.messageTypeId:= -1;
self.messageId := NonSparkTypes.messageid_t.To_Bounded_String("");
self.action := NonSparkTypes.action_t.To_Bounded_String("");
ChargingStationType.Initialize(self.chargingStation);
self.reason := BootReasonEnumType.ApplicationReset;
end Initialize;

procedure parse(msg:   in  NonSparkTypes.packet.Bounded_String;
                msgindex: out Integer;
                self: out ocpp.BootNotificationRequest.T;
                valid: out Boolean)
is
  dummybounded: NonSparkTypes.packet.Bounded_String :=
    NonSparkTypes.packet.To_Bounded_String("");
  dummyInt: integer;
begin
  Initialize(self);
  msgIndex := 1;
  ocpp.ParseMessageType(msg, self.messagetypeid, msgindex, valid);
  if (valid = false)
  then
    NonSparkTypes.put_line(
      "413 Invalid BootNotificationRequestreason messagetypeid");
    return;
  end if;

  ocpp.ParseMessageId(msg, self.messageid, msgindex, valid);
  if (valid = false)
  then
    NonSparkTypes.put_line(
      "416 Invalid BootNotificationRequestreason messageid");
    return;
  end if;

  ocpp.ParseAction(msg, msgindex, self.action, valid);
  if (valid = false)
  then
    NonSparkTypes.put_line("404 Invalid action");
    return;
  end if;
end parse;

```

```
end if;

checkValid(msg, msgindex, self, action, valid);
if (valid = false)
then
    NonSparkTypes.put_line("313 Invalid BootNotificationRequestreason");
    return;
end if;

ocpp.findQuotedKey(msg, msgIndex, valid, "chargingStation");
if (valid = false)
then
    NonSparkTypes.put_line(
        "355 Invalid BootNotificationRequestchargingStation");
    return;
end if;

ChargingStationType.parse(msg, msgindex, self.chargingStation, valid);
if (valid = false)
then
    NonSparkTypes.put_line(
        "357 Invalid BootNotificationRequestchargingStation");
    return;
end if;

ocpp.findQuotedKeyQuotedValue(msg, msgIndex, valid, "reason", dummybounded);
if (valid = false)
then
    NonSparkTypes.put_line("333 Invalid BootNotificationRequestreason");
    return;
end if;

ocpp.BootReasonEnumType.FromString(
    NonSparkTypes.packet.To_String(dummybounded), Self.reason, valid);
if (valid = false)
then
    NonSparkTypes.put_line("334 Invalid BootNotificationRequestreason");
    return;
end if;
```

```

    if (valid = false)
    then
        NonSparkTypes.put_line("365 Invalid BootNotificationRequestreason");
        return;
    end if;
    valid := true;
end parse;

procedure To_Bounded_String(Self: in T;
                             retval: out NonSparkTypes.packet.Bounded_String)
is
    dummybounded: NonSparkTypes.packet.Bounded_String :=
        NonSparkTypes.packet.To_Bounded_String("");
    strchargingStation : NonSparkTypes.packet.Bounded_String;
    strreason : BootReasonEnumType.string_t.Bounded_String;
begin
    ChargingStationType.To_Bounded_String(
        Self.chargingStation, strchargingStation);
    BootReasonEnumType.ToString(Self.reason, strreason);
    retval := NonSparkTypes.packet.To_Bounded_String("")
        & "[2," & ASCII.LF
        & ''' & NonSparkTypes.messageid_t.To_String(Self.messageid) &
        ''' & "," & ASCII.LF
        & ''' & NonSparkTypes.action_t.To_String(Self.action) &
        ''' & "," & ASCII.LF
        & "{" & ASCII.LF
        & "    " & ''' & "chargingStation" & ''' & ":" &
        NonSparkTypes.packet.To_String(strchargingStation) &
        "," & ASCII.LF
        & "        " & ''' & "reason" & ''' & ":" & ''' &
        BootReasonEnumType.string_t.To_String(strreason) &
        ''' & ASCII.LF
        & "}" & ASCII.LF
        & "]", Drop => Right);
end To_Bounded_String;
end ocpp.BootNotificationRequest;

```

In order to parse a single OCPP message type ‘BootNotificationRequest’, the code generation script created specification and implementation files for ‘BootRea-

sonEnumType', 'ChargingStationType', 'ModemType', and 'BootNotificationRequest', including the appropriate verification conditions required to prove termination and absence of interference with global data.

Chapter 4

Results and discussion

The following software quality goals were stated in the Project Proposal:

4.0.1 Software Quality Goals

Implement a minimal OCPP v2.01 server, with the following properties automatically verified:

- the absence of memory leaks
- the program should never access uninitialized memory (for example, should never read past the end of an array)
- the program should never crash or exit unexpectedly
- the tool should verify the absence of stack overflows, i.e. the program should be bounded in terms of memory (RAM) usage at runtime
- the program should verifiably meet its requirements. These requirements are typically in the form of preconditions and postconditions.
- the program should never exhibit undefined behaviour
- the program should constrain information flow, i.e. not leak sensitive information such as passwords
- The tool should be sound. Many of the tools claim to be sound “modulo bugs in the tool”, and have lengthy lists of known bugs.

4.1 Software Verification Goals

4.1.1 Automatically verify the absence of memory leaks

SPARK 2014 does not verify the absence of memory leaks. This property can be guaranteed by never allocating memory via the ‘new’ keyword, which means that memory is never allocated on the stack, only on the heap. Objects and variables declared on the heap have their memory automatically deallocated when they go out of scope. However, this property is not automatically verified by the toolset.

4.1.2 Automatically verify the absence of uninitialized memory reads

SPARK 2014 does automatically verify the absence of uninitialized memory reads. The OCPP server uses this facility to verify the absence of uninitialized memory reads.

4.1.3 Automatically prove that the program can never crash or exit unexpectedly

SPARK 2014 partially implements this. It guarantees the absence of the following runtime errors:

- the absence of explicitly raised exceptions. SPARK allows the programmer to raise exceptions, but the toolset will attempt to prove that the ‘raise’ statement will never actually execute.
- the absence of ‘Constraint_Error’ exceptions. These exceptions are raised in the following situations:
 - a value is assigned to a variable that is outside of the variable’s range constraint,
 - an attempt is made to access an ‘out of bounds’ array element,
 - arithmetic overflow.
- the absence of all possible failures of assertions corresponding to raising exception ‘Assert_Error’ at run time. For example, consider the following code:

```
procedure TestAssert (X : Integer) with
  SPARK_Mode
is
begin
```

```
pragma Assert (X > 0);
end TestAssert;
```

At runtime, if this function was called with a value of ‘X’ less than zero, an ‘Assert_Error’ would be raised. At compile time, GNATprove cannot prove the assertion, and yields the following error message:

```
TestAssert.adb:5:19: medium: assertion might fail,
cannot prove X > 0
[possible explanation: subprogram at line 1 should mention X
in a precondition]
```

The only runtime error not detected by GNATprove is the absence of ‘Storage_Error’ exceptions. These exceptions occur when a program runs out of memory, either by running out of heap space when dynamically allocating objects, or by stack overflow. Stack overflow can be caused by instantiating too many objects, or by recursive functions.

4.1.4 Automatically verify the program meets its requirements

SPARK 2014 does automatically verify that the program meets its requirements.

4.1.5 Automatically verify the absence of undefined behaviour

SPARK 2014 satisfies this goal. There are two types of undefined behaviour that SPARK inherits from Ada, ‘bounded error’ and ‘erroneous execution’. These are detected by a combination of legality rules (the compiler) and verification rules (GNATprove).

4.1.6 Automatically verify the constraint of information flow

SPARK 2014 satisfies this goal, however this feature has not been used in the OCPP server implementation.

4.1.7 Soundness

SPARK 2014 is thought to be sound. No examples of unsound behaviour were found (i.e. the program never crashed unexpectedly). In some situations, the toolset produces ‘false alarms’, where it cannot prove that something is correct. In these cases, the code was restructured to make it more amenable to verification.

4.1.8 Software Verification Goals Summary

The table below shows the original goals of this project as stated in the Project Proposal. The cells in green indicate that a goal was met, orange indicates partially met, red indicates a goal was not met.

the absence of memory leaks
the absence of uninitialized memory reads
the absence of run time exceptions
the absence of stack overflows
verifiably meets its requirements
the absence of undefined behaviour
constrains information flow
tool soundness

Table 4.1: OCPP Server Software Quality Verification Goals

4.2 Software Functionality Goals

The following table lists the OCPP functionality goals and their completion status. Green indicates complete, red indicates incomplete.

Table 4.2: Use cases for a basic implementation

Functionality	Use Case	Messages	Complete
Booting a charge station	B01 - B04	BootNotification	
Configuring a charge station	B05-B07	SetVariables, GetVariables, GetReportBase	
Resetting a charge station	B11-B12	Reset	
Authorization Options	One of C01, C02, C04	Authorize	
Transaction Mechanism	E01 (one of S1-S6), E02-E03, E05, E06 (one of S1-S6), E07- E08, One of E09-E10, E11-E13	TransactionEvent	
Availability	G01, G03-G04	ChangeAvailability, StatusNotification	
Monitoring Events	G05, N07	NotifyEvent	
Meter Values	J02	TransactionEvent	
Data Transfer	P01-P02	DataTransfer	

Not all tasks were able to be completed in the given time. There was a significant learning curve in becoming proficient with the SPARK 2014 toolset, both in learning the language and in learning how to effectively use GNATprove to discharge verification conditions.

4.3 SPARK 2014

The experience with SPARK 2014 was on the whole an extremely positive one. The software developer can choose what level of software assurance to adopt, from ‘stone’ (valid SPARK) through to ‘platinum’ (all data initialized, correct data flow, absence

of run time errors, full functional correctness). In the author's opinion, 'silver' (all data initialized, correct data flow, absence of run time errors) yields the greatest gains for the effort required. SPARK can be considered a 'better C++', and its use is recommended anywhere quality is important.

4.3.1 Pros

- gives a level of quality impossible to attain with mainstream programming languages, especially in larger codebases
- the toolset automatically detects all possible run time exceptions, excluding 'out of memory' conditions
- the 'community' edition is free for GPL development
- likely to reduce costs over the lifetime of a software project

4.3.2 Cons

- lengthy learning curve
- productivity 'appears' to be lower with SPARK than with a mainstream language, as most (all?) of the bugs are discovered and resolved earlier in the software lifecycle.
- very limited pool of software developers with SPARK experience makes it less likely that it will be chosen for new projects
- Commercial license pricing is opaque, and is unlikely to be cheap

Chapter 5

Conclusions

5.1 Summary and conclusions

During the course of this project, an OCPP v2.1 server was partially implemented, with several important properties automatically verified by the SPARK 2014 toolset. These properties include the verified absence of all runtime exceptions, excluding ‘out of memory’ exceptions.

An automated code generator was developed which exploits existing JSON definition files to create formally verified serializing and deserializing routines for arbitrarily deeply nested JSON data.

5.2 Possible future work

The following improvements could be made to improve the OCPP server.

- Complete the remaining use cases required for a minimal OCPP server implementation described in Table [4.2](#)
- Implement all packets described in the OCPP specification [\[70\]](#).
- Extend the functional correctness proofs to verify more of the desired functionality.

Appendix

A.1 Dafny

Repro: Here is the output on the program below:

```
Dafny program verifier finished with 2 verified, 0 errors
Running...
```

60

And here is the program:

```
trait Tr {
  var x: int
}

class C extends Tr {
  var y: int
}

class D extends Tr {
  var z: int
}

method M(t: Tr)
  modifies t
{
  print "t.x=", t.x, " ";
  var s: set<C> := set c: C | c == t; // this line crashes for the call M(d)
  if s == {} {
%    print "The given Tr is not a C\n";
  } else {
    var c :| c in s;
%    print "The given Tr is a C, and c.y=", c.y, "\n";
    c.y := c.y + 10;
  }
}

method Main() {
  var c := new C;
  var d := new D;
  c.x, c.y := 5, 6;
  d.x, d.z := 100, 102;

  M(c);
  M(d);
}
```

```
M(c);  
}
```

<https://gitter.im/dafny-lang/community?at=5d90c402086a72719e848f24>

Bryan Parno

@parno

Mar 14 05:41

We use reference counting via `shared_ptr` Which means it is possible to create memory

Appendix B

BootNotificationRequest.js

The following is an example of the JSON definition for an OCPP packet. These definition files were part of the OCPP download bundle.

```
{
  "$schema": "http://json-schema.org/draft-06/schema#",
  "$id": "urn:OCPP:Cp:2:2019:12:BootNotificationRequest",
  "comment": "Errata sheet - release candidate",
  "definitions": {
    "CustomDataType": {
      "description": "This class does not get 'AdditionalProperties =
        false'
in the schema generation, so it can be extended with arbitrary
JSON
properties to allow adding custom data.",
      "javaType": "CustomData",
      "type": "object",
      "properties": {
        "vendorId": {
          "type": "string",
          "maxLength": 255
        }
      },
      "required": [
        "vendorId"
      ]
    },
    "BootReasonEnumType": {
      "description": "This contains the reason for sending this message
```

```

to the CSMS.\r\n",
"javaType": "BootReasonEnum",
"type": "string",
"additionalProperties": false,
"enum": [
  "ApplicationReset",
  "FirmwareUpdate",
  "LocalReset",
  "PowerUp",
  "RemoteReset",
  "ScheduledReset",
  "Triggered",
  "Unknown",
  "Watchdog"
]
},
"ChargingStationType": {
  "description": "Charge_ Point\r\nurn:x-oca:ocpp:uid:2:233122\r\n
The physical system where an Electrical Vehicle (EV) can be
charged.\r\n",
"javaType": "ChargingStation",
"type": "object",
"additionalProperties": false,
"properties": {
  "customData": {
    "$ref": "#/definitions/CustomDataType"
  },
  "serialNumber": {
    "description": "Device. Serial_ Number. Serial_ Number\r\n
urn:x-oca:ocpp:uid:1:569324\r\nVendor-specific device
identifier.\r\n",
"type": "string",
"maxLength": 25
  },
  "model": {
    "description": "Device. Model. CI20_ Text\r\n
urn:x-oca:ocpp:uid:1:569325\r\nDefines the model of the
device.\r\n",
"type": "string",

```

```

        "maxLength": 20
    },
    "modem": {
        "$ref": "#/definitions/ModemType"
    },
    "vendorName": {
        "description": "Identifies the vendor (not necessarily
            in a unique manner).\r\n",
        "type": "string",
        "maxLength": 50
    },
    "firmwareVersion": {
        "description": "This contains the firmware version of the
            Charging Station.\r\n\r\n",
        "type": "string",
        "maxLength": 50
    }
},
"required": [
    "model",
    "vendorName"
]
},
"ModemType": {
    "description": "Wireless_ Communication_ Module\r\n
urn:x-oca:ocpp:uid:2:233306\r\nDefines parameters required
    for initiating and maintaining wireless communication
    with other devices.\r\n",
    "javaType": "Modem",
    "type": "object",
    "additionalProperties": false,
    "properties": {
        "customData": {
            "$ref": "#/definitions/CustomDataType"
        }
    },
    "iccid": {
        "description": "Wireless_ Communication_ Module. ICCID.
            CI20_ Text\r\nurn:x-oca:ocpp:uid:1:569327\r\n
            This contains the ICCID of the modem's SIM card.\r\n",

```

```

        "type": "string",
        "maxLength": 20
    },
    "imsi": {
        "description": "Wireless_ Communication_ Module. IMSI.
        CI20_ Text\r\n
        urn:x-oca:ocpp:uid:1:569328\r\nThis contains the IMSI
        of the modem's SIM card.\r\n",
        "type": "string",
        "maxLength": 20
    }
}
},
"type": "object",
"additionalProperties": false,
"properties": {
    "customData": {
        "$ref": "#/definitions/CustomDataType"
    },
    "chargingStation": {
        "$ref": "#/definitions/ChargingStationType"
    },
    "reason": {
        "$ref": "#/definitions/BootReasonEnumType"
    }
},
"required": [
    "reason",
    "chargingStation"
]
}

```


Appendix C

Companion disk

The source code for this project exceeds 12000 lines of code, so it has not been included here. Full source is available at <https://github.com/DanielMcInnes/thesis.git>.

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