CHAPTER

THIRTEEN

LOW-RATE WIRELESS PERSONAL AREA NETWORK (LR-WPAN)

This chapter describes the implementation of ns-3 models for the low-rate, wireless personal area network (LR-WPAN) as specified by IEEE standard 802.15.4 (2006).

13.1 Model Description

The source code for the lr-wpan module lives in the directory `src/lr-wpan`.

13.1.1 Design

The model design closely follows the standard from an architectural standpoint.

The grey areas in the figure (adapted from Fig 3. of IEEE Std. 802.15.4-2006) show the scope of the model.

The Spectrum NetDevice from Nicola Baldo is the basis for the implementation.

The implementation also plans to borrow from the ns-2 models developed by Zheng and Lee in the future.

APIs

The APIs closely follow the standard, adapted for ns-3 naming conventions and idioms. The APIs are organized around the concept of service primitives as shown in the following figure adapted from Figure 14 of IEEE Std. 802.15.4-2006.

The APIs are organized around four conceptual services and service access points (SAP):

- MAC data service (MCPS)
- MAC management service (MLME)
- PHY data service (PD)
- PHY management service (PLME)

In general, primitives are standardized as follows (e.g. Sec 7.1.1.1.1 of IEEE 802.15.4-2006)::

```
MCPS-DATA.request       (
                         SrcAddrMode,
                         DstAddrMode,
                         DstPANId,
```

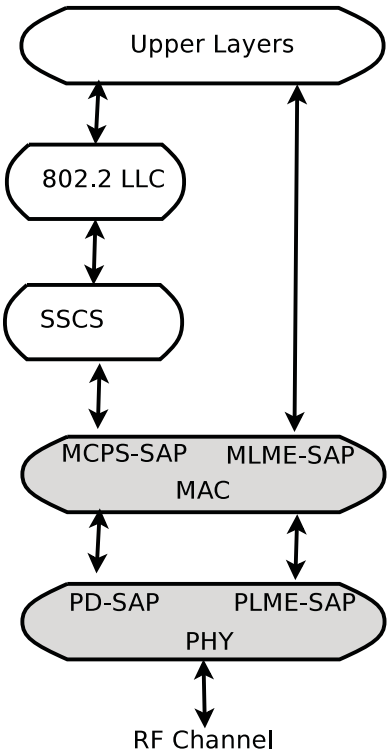

Figure 13.1: Architecture and scope of lr-wpan models

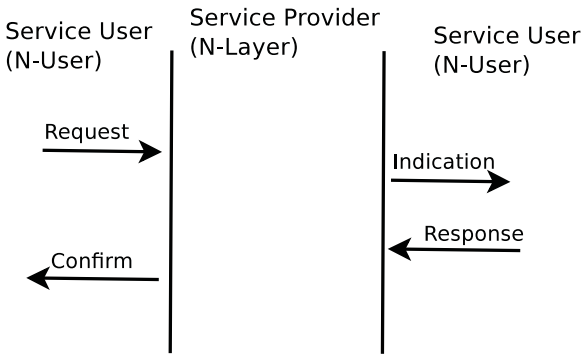

Figure 13.2: Service primitives

```
                        DstAddr,
                        msduLength,
                        msdu,
                        msduHandle,
                        TxOptions,
                        SecurityLevel,
                        KeyIdMode,
                        KeySource,
                        KeyIndex
                        )
```

This maps to ns-3 classes and methods such as::

```
struct McpsDataRequestParameters
{
  uint8_t m_srcAddrMode;
  uint8_t m_dstAddrMode;
  ...
};

void
LrWpanMac::McpsDataRequest (McpsDataRequestParameters params)
{
...
}
```

MAC

The MAC at present implements the unslotted CSMA/CA variant, without beaconing. The main API supported is the data transfer API (McpsDataRequest/Indication/Confirm). CSMA/CA according to Stc 802.15.4-2006, section 7.5.1.4 is supported. Frame reception and rejection according to Std 802.15.4-2006, section 7.5.6.2 is supported. Various trace sources are supported, and trace sources can be hooked to sinks.

PHY

The physical layer components consist of a Phy model, an error rate model, and a loss model. The error rate model presently models the error rate for IEEE 802.15.4 2.4 GHz AWGN channel for OQPSK; the model description can be found in IEEE Std 802.15.4-2006, section E.4.1.7. The Phy model is based on SpectrumPhy and it follows specification described in section 6 of IEEE Std 802.15.4-2006. It models PHY service specifications, PPDU formats, PHY constants and PIB attributes. It currently only supports the transmit power spectral density mask specified in 2.4 GHz per section 6.5.3.1. The noise power density assumes uniformly distributed thermal noise across the frequency bands. The loss model can fully utilize all existing simple (non-spectrum phy) loss models. The Phy model uses the existing single spectrum channel model.

NetDevice

Although it is expected that other technology profiles (such as 6LoWPAN and ZigBee) will write their own NetDevice classes, a basic LrWpanNetDevice is provided, which encapsulates the common operations of creating a generic LrWpan device and hooking things together.

13.1.2 Scope and Limitations

Future versions of this document will contain a PICS proforma similar to Appendix D of IEEE 802.15.4-2006. The current emphasis is on the unslotted mode of 802.15.4 operation for use in Zigbee, and the scope is limited to enabling a single mode (CSMA/CA) with basic data transfer capabilities.

13.1.3 References

- Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), IEEE Computer Society, IEEE Std 802.15.4-2006, 8 September 2006.
- 10. Zheng and Myung J. Lee, "A comprehensive performance study of IEEE 802.15.4," Sensor Network Operations, IEEE Press, Wiley Interscience, Chapter 4, pp. 218-237, 2006.

13.2 Usage

13.2.1 Enabling lr-wpan

Add `lr-wpan` to the list of modules built with ns-3.

13.2.2 Helper

The helper is patterned after other device helpers. In particular, tracing (ascii and pcap) is enabled similarly, and enabling of all lr-wpan log components is performed similarly. Use of the helper is exemplified in `examples/lr-wpan-data.cc`. For ascii tracing, the transmit and receive traces are hooked at the Mac layer.

The default propagation loss model added to the channel, when this helper is used, is the LogDistancePropagationLossModel.

13.2.3 Examples

The following examples have been written, which can be found in `src/lr-wpan/examples/`:

- `lr-wpan-data.cc`: A simple example showing end-to-end data transfer.
- `lr-wpan-error-model-plot.cc`: An example to test the phy.
- `lr-wpan-error-distance-plot.cc`: An example to plot variations of the packet success ratio as a function of distance.
- `lr-wpan-packet-print.cc`: An example to print out the MAC header fields.
- `lr-wpan-phy-test.cc`: An example to test the phy.

In particular, the module enables a very simplified end-to-end data transfer scenario, implemented in `lr-wpan-data.cc`. The figure shows a sequence of events that are triggered when the MAC receives a DataRequest from the higher layer. It invokes a Clear Channel Assessment (CCA) from the PHY, and if successful, sends the frame down to the PHY where it is transmitted over the channel and results in a DataIndication on the peer node.

The example `lr-wpan-error-distance-plot.cc` plots the packet success ratio (PSR) as a function of distance, using the default LogDistance propagation loss model and the 802.15.4 error model. The channel (default 11), packet size (default 20 bytes) and transmit power (default 0 dBm) can be varied by command line arguments. The program outputs a file named `802.15.4-psr-distance.plt`. Loading this file into gnuplot yields a file

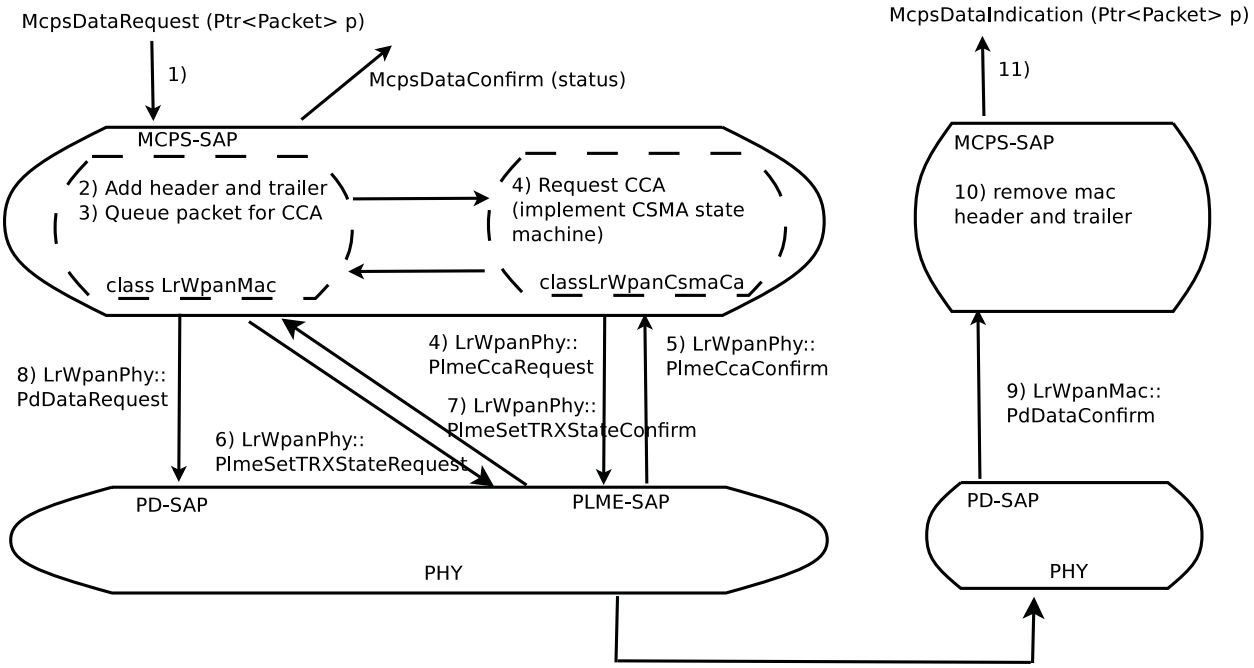

Figure 13.3: Data example for simple LR-WPAN data transfer end-to-end

`802.15.4-psr-distance.eps`, which can be converted to pdf or other formats. The default output is shown below.

13.2.4 Tests

The following tests have been written, which can be found in `src/lr-wpan/tests/`:

- `lr-wpan-error-model-test.cc`: Check that the error model gives predictable values.
- `lr-wpan-packet-test.cc`: Test the 802.15.4 MAC header/trailer classes
- `lr-wpan-pd-plme-sap-test.cc`: Test the PLME and PD SAP per IEEE 802.15.4
- `lr-wpan-spectrum-value-helper-test.cc`: Test that the conversion between power (expressed as a scalar quantity) and spectral power, and back again, falls within a 25% tolerance across the range of possible channels and input powers.

13.3 Validation

The model has not been validated against real hardware. The error model has been validated against the data in IEEE Std 802.15.4-2006, section E.4.1.7 (Figure E.2). The MAC behavior (CSMA backoff) has been validated by hand against expected behavior. The below plot is an example of the error model validation and can be reproduced by running `lr-wpan-error-model-plot.cc`:

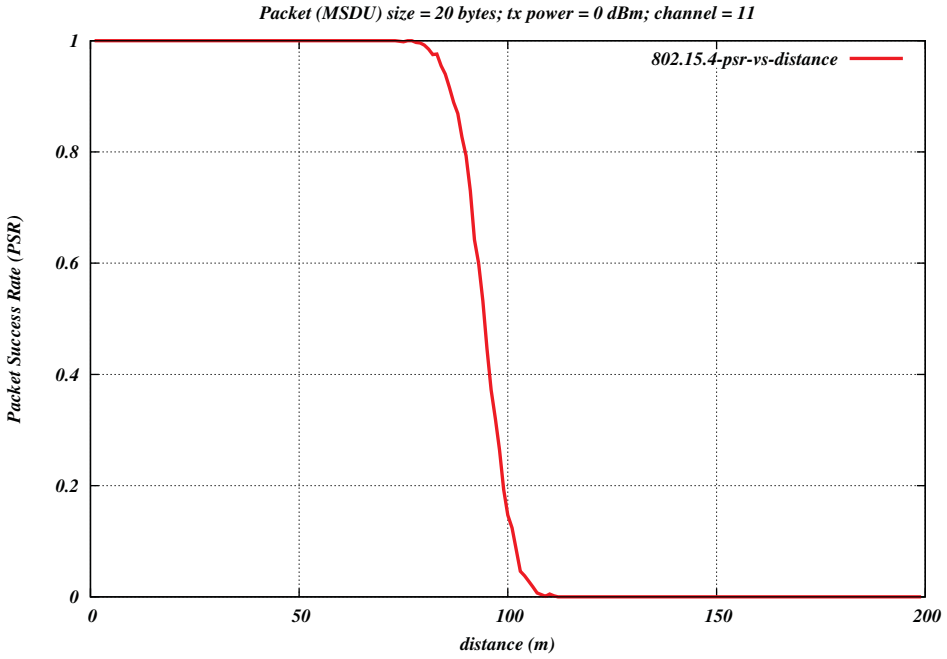

Figure 13.4: Default output of the program `lr-wpan-error-distance-plot.cc`

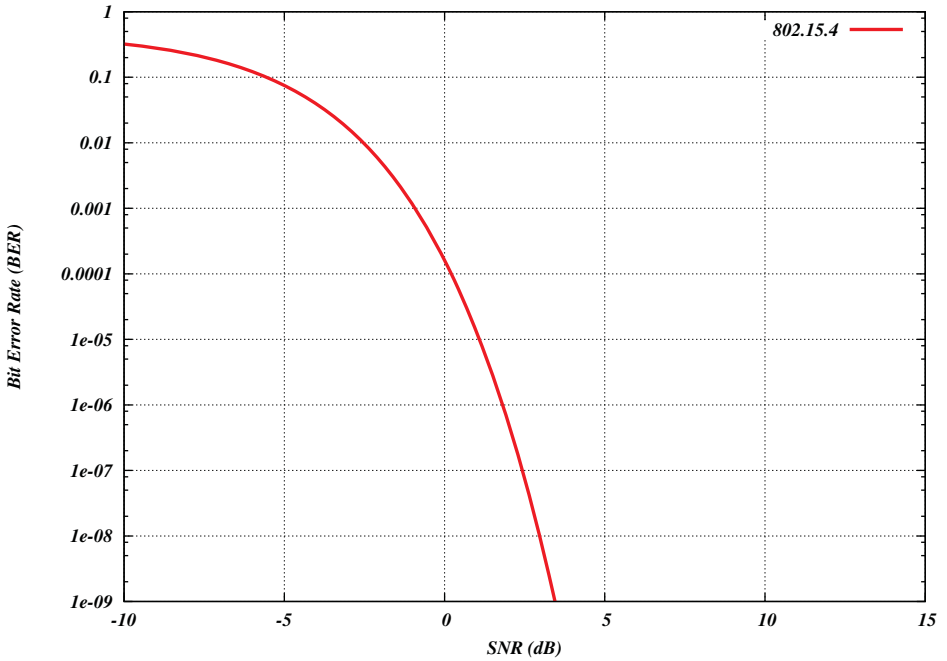

Figure 13.5: Default output of the program `lr-wpan-error-model-plot.cc`