WiFi and Secure Socket Offload in Zephyr™

Gil Pitney / Texas Instruments
gpitney@ti.com
Motivation

- The TI SimpleLink CC32xx family of MCUs provides an SoC and supporting SDK which completely offloads the WiFi stack onto an integrated network coprocessor (NWP).
  - This provides significant memory, CPU, and energy savings.
  - All secure communications, certificate/key storage, crypto and power management is handled on the NWP.
  - The SimpleLink SDK has no support for the Zephyr OS, but is designed to be portable.
- Zephyr networking stack has support for WiFi via an offload tap (data plane), and wifi management events (control plane).
- **The goal is to efficiently integrate the full SimpleLink offload capabilities into Zephyr, while still leveraging Zephyr networking applications and protocols.**
  - All work done on the **CC3220SF-LaunchXL** Development board.
TI CC3220SF SoC H/W Architecture
TI SimpleLink CC32xx SDK Architecture & APIs

- **Device API**: Manages hardware-related functionality such as start, stop, set, and get device configurations.
- **WLAN API**: Manages WLAN, 802.11 protocol-related functionality such as device mode (station, AP, or P2P), provisioning method, connection profiles, and connection policy.
- **BSD Socket API**: Standard API, but TLS handled under the Socket API.
- **NetApp API**: Enables offload networking servers (HTTP, DHCP, mDNS).
- **NetCfg API**: Configures network parameters (MAC address, acquiring IP address by DHCP, setting the static IP address).
- **Serial Flash API**: for networking or user proprietary data.

Sources: swru368, swru369c
Zephyr Network Stack (Previous State)

- Plan has been to support WiFi via offload chips.
  - No WiFi L2 Drivers
  - No WiFi supplicant, or provisioning support (yet).
- Secure comms (SSL/TLS) provided by mbedTLS library
Options for Offloading to the WiFi coprocessor (1/2)

Option 1: Full TCP/IP Offload:
- How:
  - Port SimpleLink NWP driver -> Zephyr
  - `#include <SL_SDK>/simplelink.h`
  - `#include <SL_SDK>/sys/socket.h`
- Pros:
  - Offers fullest H/W entitlement.
  - Zephyr apps get full access to SimpleLink WLAN, NetApp, Socket APIs.
- Cons:
  - No integration with Zephyr WiFi event management.
  - Will not leverage Zephyr’s socket-based network protocols.

Option 2: Write an L2 Driver:
- How:
  - Use SimpleLink Raw Sockets.
  - Implement L2 send(), reserve() fxns.
  - Push received data via net_pkt to Zephyr IP core.
- Pros:
  - Hooks deeply into the Zephyr IP Core.
  - Enables Zephyr use cases like packet routing across network interfaces.
- Cons:
  - Does not leverage SimpleLink:
    - network buffer allocation, management
    - DHCP, DNS offloaded
    - Secure socket offloading
Options for Offloading to the WiFi coprocessor (2/2)

Option 3: Offload at net_context():

- **How:**
  - Enable `CONFIG_NET_OFFLOAD`
  - Write a full Zephyr WiFi driver

- **Pros:**
  - TCP/IP is offloaded to the coprocessor.
  - Enables Zephyr use cases like packet routing across network interfaces.

- **Cons:**
  - Overheads:
    - Mapping sync BSD socket APIs to async `net_context` APIs and back.
    - Received data copied into `net_bufs` and queued.
    - Driver thread to poll sockets and trigger callbacks

Option 4: Offload at BSD socket layer:

- **How:**
  - Enable `CONFIG_NET_SOCKETS_OFFLOAD`
  - Write a Zephyr WiFi driver (control only)
  - Register offloaded socket fxns w/ Zephyr.

- **Pros:**
  - Avoids overheads of Option 3)
  - Secure socket communications get fully offloaded.
  - DNS offloaded too (`getaddrinfo()`)

- **Cons:**
  - Currently, only one socket provider in the system
  - No packet routing across net interfaces.
Zephyr Network Stack (New State)

- Protocols being migrated from net_app/net_context to BSD sockets.
- TLS added to socket APIs
- wifi_mgmt handles scan, connect/disconnect events
- New WiFi net offload drivers
- New offload tap at BSD socket layer, allowing full secure socket offload.

Zephyr Network Protocols (MQTT, LwM2M,...)

BSD sockets & TLS setsockopt()

ifdef CONFIG_NET_SOCKETS_OFFLOAD

mbedTLS library

ifdef CONFIG_NET_OFFLOAD

TI SimpleLink WiFi Driver / Socket Provider

net_mgmt

net_context

Zephyr Native IP Stack

L2 Interface

Drivers

Atmel Winc1500 WiFi driver

es-WiFi, ESP8266 WiFi drivers (PRs)
Zephyr Socket APIs + TLS

● Why?
  ○ TLS is hard to get right; many TLS library APIs and configuration options.
  ○ Should make it easy to add TLS to non-secure socket-based networking apps/protocols.

● Adding TLS to a networking app via mbedTLS involves:
  ○ Creation/initialization of mbedtls ssl, config contexts, registration of entropy generator.
  ○ Certificates setup.
  ○ Socket creation (standard POSIX); then connection via mbedtls_net_connect()
  ○ Configuration of the TLS/SSL layer.
    ■ Set server/client mode
    ■ Set certificate authentication mode
    ■ Specify RNG and DBG functions
    ■ Set network tx/rx functions via mbedtls_ssl_set_bio()
  ○ Read/Write via mbedtls_ssl_read()/mbedtls_ssl_write()
  ○ Teardown of mbedtls contexts.

● Zephyr wrapped all this with net_app, but we want to leverage standard APIs...
Idea: Encapsulate TLS under POSIX Socket APIs

```c
#include <net/socket.h>

hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;
getaddrinfo(HTTP_HOST, HTTP_PORT, &hints, &res);

#if defined(CONFIG_NET_SOCKETS_SOCKOPT_TLS)
sock = socket(res->ai_family, res->ai_socktype, IPPROTO_TLS_1_2);

setsockopt(sock, SOL_TLS, TLS_SEC_TAG_LIST, sec_tag_opt, sizeof(sec_tag_opt));
setsockopt(sock, SOL_TLS, TLS_HOSTNAME, HTTP_HOST, sizeof(HTTP_HOST))
#endif /* CONFIG_NET_SOCKETS_SOCKOPT_TLS */

connect(sock, res->ai_addr, res->ai_addrlen);
send(sock, REQUEST, SSTRLEN(REQUEST), 0);
recv(sock, response, sizeof(response) - 1, 0);
close(sock);
```
Also, need to “provision” certificates/keys up front

/* In main() somewhere at program initialization: */

#if defined(CONFIG_NET_SOCKETS_SOCKOPT_TLS)
#include <net/tls_credentials.h>

#define CA_CERTIFICATE_TAG 1
/* GlobalSign Root CA - R2 for https://google.com */
static const unsigned char ca_certificate[] = {
#include "globalsign_r2.der.inc"
}

tls_credential_add(CA_CERTIFICATE_TAG, TLS_CREDENTIAL_CA_CERTIFICATE,
                    ca_certificate, sizeof(ca_certificate));

sec_tag_t sec_tag_opt[] = {
    CA_CERTIFICATE_TAG,
};

#endif /* CONFIG_NET_SOCKETS_SOCKOPT_TLS */
Provisioning Certificates/Keys on CC3220SF

TI UniFlash Tool:
- Burns certificates/private keys into secure flash.
- Keeps a catalog of Trusted Root Certificates
- Eg: Add the cloud server’s root certificate to secure flash.

At runtime:
- bind certificate’s filename to client socket using `setsockopt()`
- MCU apps have no access to the “secrets”.

For CC3220SF, only need provide cert/key filenames

```c
#include <net/tls_credentials.h>

#define CA_CERTIFICATE_TAG 1

/* GlobalSign Root CA - R2 for https://google.com */
static const unsigned char ca_certificate[] = "global_sign_root_ca_cert"

/* Rest of networking application is the same: */
tls_credential_add(CA_CERTIFICATE_TAG, TLS_CREDENTIAL_CA_CERTIFICATE,
                   ca_certificate, sizeof(ca_certificate));
sec_tag_t sec_tag_opt[] = {
    CA_CERTIFICATE_TAG,
};

...
Summary

- The **TI SimpleLink CC3220SF SoC** allows the TCP/IP stack, WiFi, secure communications, encryption, secrets storage and power management to be offloaded from the MCU (Zephyr) to an integrated network coprocessor (NWP).

- The SimpleLink SDK’s “NWP driver” is ported to Zephyr via a thin OSAL.
- A SimpleLink Zephyr WiFi driver implements the wifi_mgmt API, and sends connect/disconnect/scan notifications back to the network event manager.
- Certificates are provisioned to CC3220SF **secure flash** offline via TI UniFlash.
- The SimpleLink Zephyr WiFi driver hooks into the (new) **Zephyr socket offload tap**, and with the help of Zephyr’s TLS addition to the BSD APIs, can achieve **fully secure socket offload**, available to Zephyr **socket-based** net protocols.
Thank You!