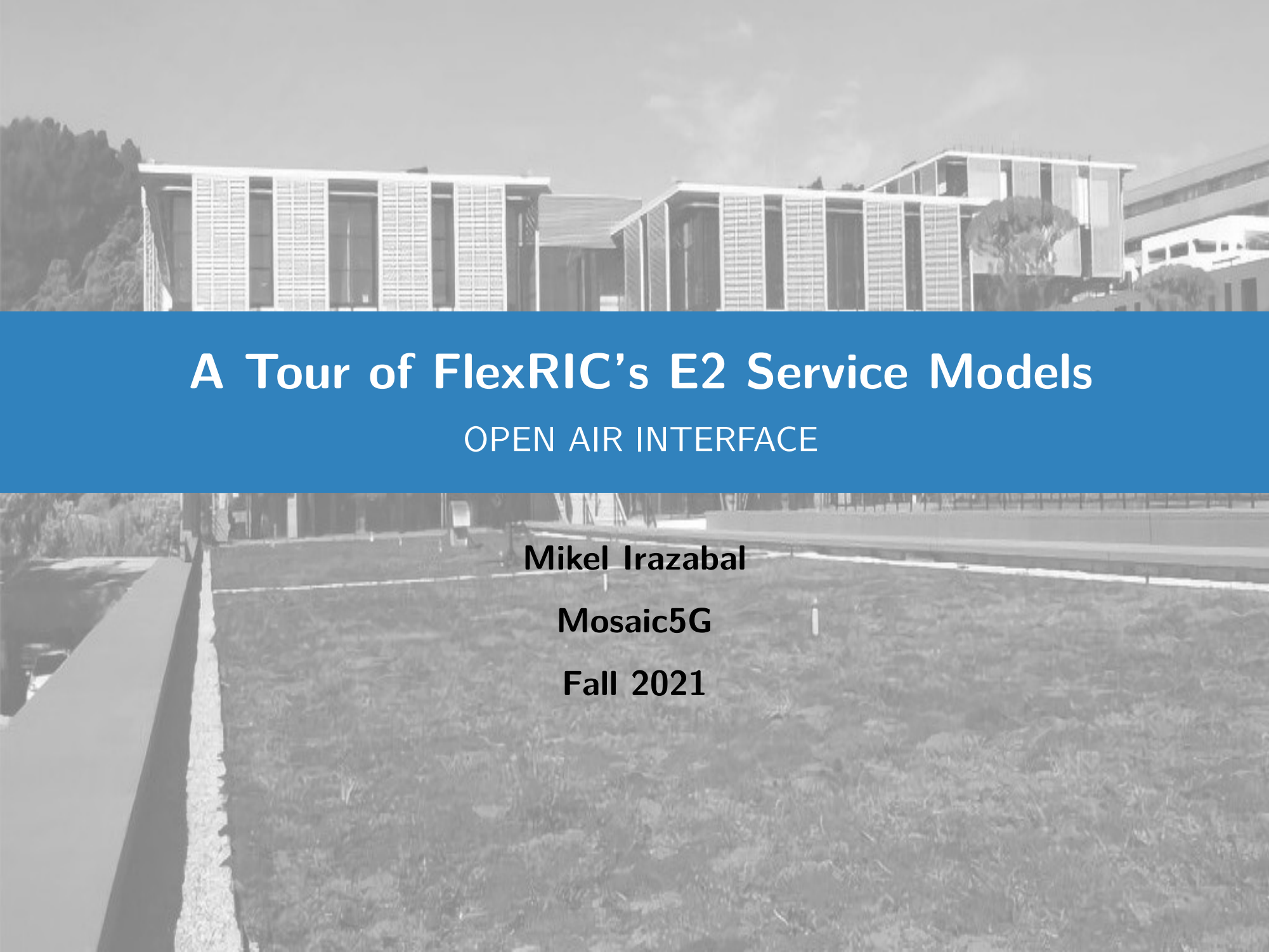

A Tour of FlexRIC's E2 Service Models

OPEN AIR INTERFACE

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0 Outline

1 Outline

1 RIC Services, E2AP Procedures and E2AP Information Elements

- The E2 interface is composed of RIC Services, E2AP Procedures and E2AP Information Elements (IE)
- There exists 4 RIC Services i.e., Report, Insert, Control and Policy
  - Each Service, is composed of various E2AP Procedures
- There exists 26 E2AP Procedures
  - 10 messages for Near-RT RIC Functional Procedures e.g., RIC Subscription Request, RIC Indication
  - 16 messages for Global Procedures e.g., E2 Setup Request, RIC Service Update
    - Each E2AP, is composed of various E2AP IE
- There exists 32 E2AP IE e.g., Global RIC ID, RIC Indication Header

1 Example: Report RIC Service

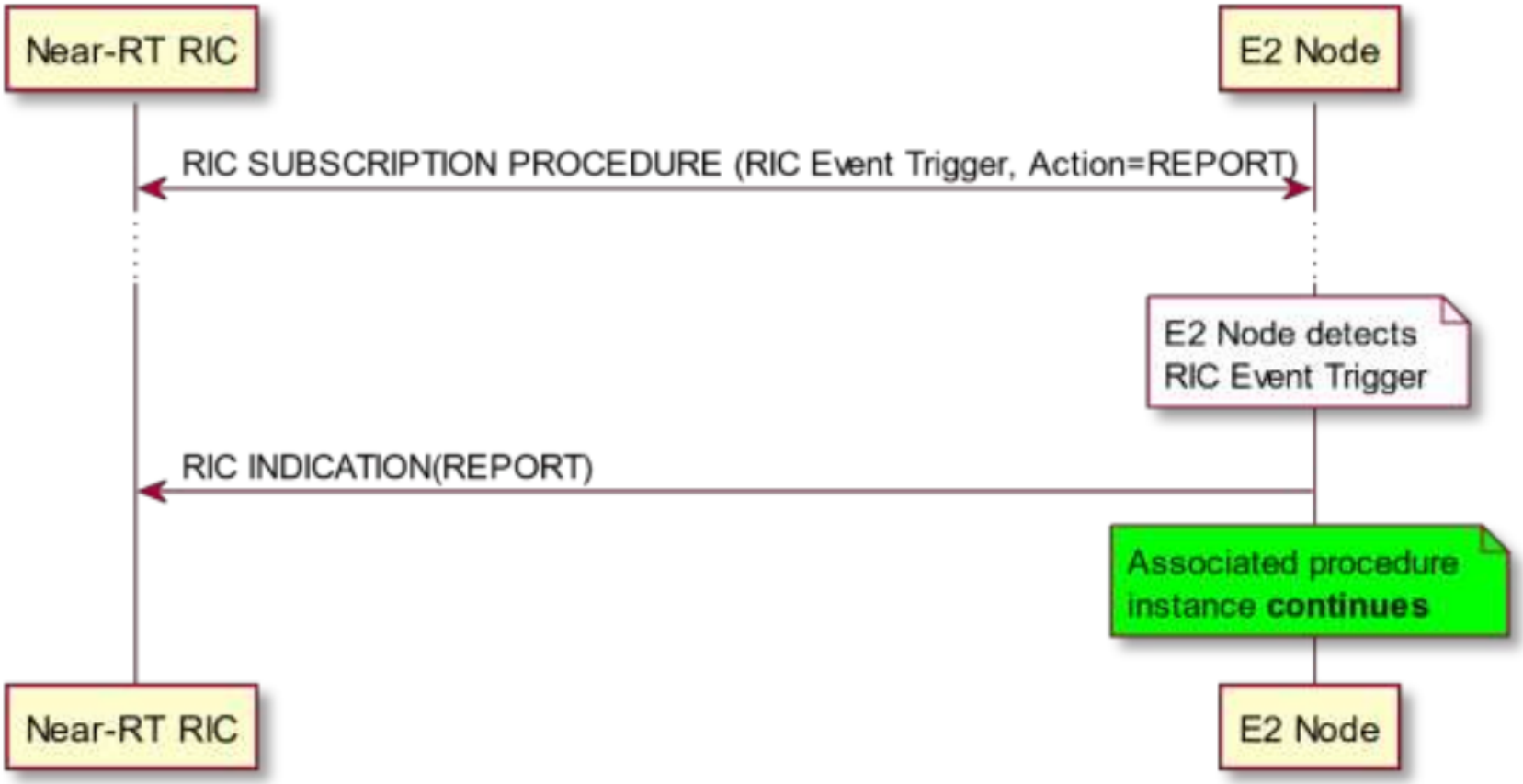


Figure: Report Service message sequence chart

1 Example: E2AP RIC Indication Procedure and IE

IE/Group Name	Presence	Range	IE type and reference	Semantics description	Criticality	Assigned Criticality
Message Type	M		9.2.3		YES	reject
RIC Request ID	M		9.2.7		YES	reject
RAN Function ID	M		9.2.8		YES	reject
RIC Action ID	M		9.2.10		YES	reject
RIC Indication SN	O		9.2.14		YES	reject
RIC Indication Type	M		9.2.15		YES	reject
RIC Indication Header	M		9.2.17		YES	reject
RIC Indication Message	M		9.2.16		YES	reject
RIC Call process ID	O		9.2.18		YES	reject

Figure: E2AP RIC Indication Message Procedure definition

IE/Group Name	Presence	Range	IE type and reference	Semantics description
RIC Requestor ID	M		INTEGER (0.. 65535)	
RIC Instance ID	M		INTEGER (0..65535)	

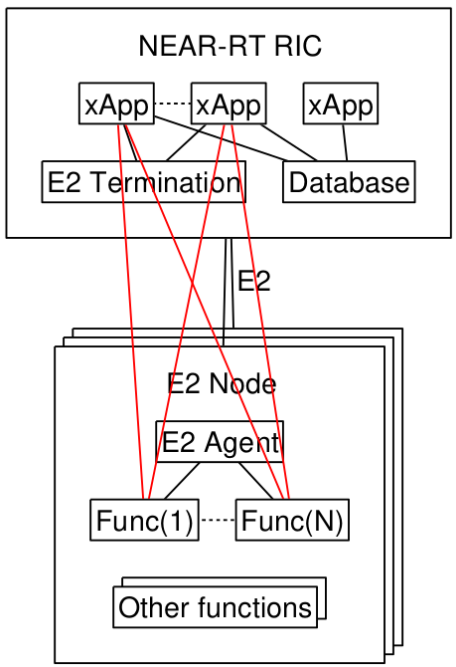
Figure: RIC Request ID IE definition

1 O-RAN E2 Interface Summary

- The E2 Interface is composed by Services, Procedures and IE
  - Services are composed by many procedures
  - Procedures are composed by many Information Elements
  - IEs define the type and the valid ranges of the data

2 Outline

- **Definition of E2 Service Model:** The description of the Services exposed by a specific RAN function within an E2 node over the E2 interface towards the Near-RT RIC
  - E2 interface is used to carry messages between a given RAN Function and the Near-RT RIC.
  - These messages are RAN Function specific and are described in the corresponding RAN Function specific E2 Service Model.



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RIC Indication Message	M		9.2.16		YES	reject
RIC Call process ID	O		9.2.18		YES	reject

Figure: E2AP RIC Indication Message Procedure definition

IE/Group Name	Presence	Range	IE type and reference	Semantics description
RIC Indication message	M		OCTET STRING	Defined in RAN Function specific E2 Service Model [3]

Figure: RIC Indication Message IE definition

2 E2SM related E2AP Procedures and IE

- There are 5 E2AP Procedures that a SM should provide
- There are 9 IE that a E2SM should provide

RAN Function specific E2AP Information Elements	E2AP Information Element reference	Related E2AP Procedures
RIC Event Trigger Definition IE	E2AP [3] section 9.2.9	RIC Subscription
RIC Action Definition IE	E2AP [3] section 9.2.12	RIC Subscription
RIC Indication Header IE	E2AP [3] section 9.2.17	RIC Indication
RIC Indication Message IE	E2AP [3] section 9.2.16	RIC Indication
RIC Call Process ID IE	E2AP [3] section 9.2.18	RIC Indication RIC Control
RIC Control Header IE	E2AP [3] section 9.2.20	RIC Control
RIC Control Message IE	E2AP [3] section 9.2.19	RIC Control
RIC Control Outcome IE	E2AP [3] section 9.2.25	RIC Control
RAN Function Definition IE	E2AP [3] section 9.2.23	E2 Setup RIC Service Update

Figure: Relationship between E2AP Procedures and IE of a SM

2 O-RAN E2 Service Models Summary

- SM exposes the information of a specific RAN function over the E2 interface towards the Near-RT RIC
- E2SM information is embedded within a E2AP Procedure as raw bytes
- Every SM provides the semantic to interpret the data of 9 IE that are transported within 5 procedures
- E2 interface enables decoupling the protocol i.e., E2AP from the data, which is interpreted by the E2SMs

3 Outline

- SM are designed as plug-ins (shared dynamic libraries)
- SMs need to be loaded in the Near-RT RIC, as well as in the E2 Agent
- SM are built through the Factory Method Pattern, and thus, their procedures are their interface

```
#ifndef PDCP_SERVICE_MODEL_AGENT_H
#define PDCP_SERVICE_MODEL_AGENT_H

#include <stddef.h>
#include <stdint.h>

#include "../sm_agent.h"

sm_agent_t* make_pdcp_sm_agent(sm_io_ag_t io);

#endif
```

Figure: PDCP SM Factory Pattern function

- SMs communicate with the RAN through a read and write functions that is provided in construction, which facilitates its portability

```
////////////////////////////////////
//// Init the E2 Agent
  const char server_ip_str[] = "127.0.0.1";

  const gNB_RRC_INST* rrc = RC.nrrrc[mod_id];
  assert(rrc);

  const int mcc = rrc->configuration.mcc[0]; // 208;
  const int mnc =  rrc->configuration.mnc[0]; // 94;
  const int mnc_digit_len = rrc->configuration.mnc_digit_length[0]; // 2;
  const int nb_id = rrc->configuration.cell_identity; //42;
  sm_io_ag_t io = {.read = read_RAN, .write = write_RAN};

  init_agent_api(server_ip_str, mcc, mnc, mnc_digit_len, nb_id, io);
////////////////////////////////////
////////////////////////////////////
```

```
+target_link_libraries (nr-softmodem pthread m ${CONFIG_LIB} rt crypt ${CRYPTO_LIBRARIES} ${OPENSSL_LIBRARIES}
sctp  ${XFORMS_LIBRARIES} ${PROTOBUF_LIB}  ${CMAKE_DL_LIBS} ${LIBYAML_LIBRARIES} ${ATLAS_LIBRARIES})
+target_link_libraries (nr-softmodem pthread m ${CONFIG_LIB} rt crypt ${CRYPTO_LIBRARIES} ${OPENSSL_LIBRARIES}
sctp ${XFORMS_LIBRARIES} ${PROTOBUF_LIB}  ${CMAKE_DL_LIBS} ${LIBYAML_LIBRARIES} ${ATLAS_LIBRARIES}
+ ${OPENAIR_DIR}/executables/if_sm/libflexric_agent.a )
```

Figure: FlexRIC E2 Agent initialization in OAI and CMakeLists.txt diff

- SMs provide the 5 procedures and the 9 IEs specified by O-RAN

```
typedef struct {
  sm_subs_data_t (*on_subscription)(sm_ric_t const* ,const char* cmd);
  sm_rd_if_t (*on_indication)(sm_ric_t const*, sm_ind_data_t* data);
  sm_ctrl_data_t (*on_control)( sm_ric_t const*, const char* );
  void (*on_e2_setup)(sm_ric_t const*, const sm_e2_setup_t*);
  sm_ric_service_update_t (*on_ric_service_update)(sm_ric_t const*, const char*);
} sm_e2ap_procedures_ric_t;
typedef struct sm_ric_s {
```

Figure: 5 Procedures defined in the SM for the RIC

- The SMs offer a C based struct definition, that it is used as data IR

```
/////////////////////////////////////
// RIC Indication Message
/////////////////////////////////////

typedef struct{
  uint32_t txpdu_pkts;     /* aggregated number of tx packets */
  uint32_t txpdu_bytes;    /* aggregated bytes of tx packets */
  uint32_t txpdu_sn;       /* current sequence number of last tx packet (or TX_NEXT) */
  uint32_t rxpdu_pkts;     /* aggregated number of rx packets */
  uint32_t rxpdu_bytes;    /* aggregated bytes of rx packets */
  uint32_t rxpdu_sn;       /* current sequence number of last rx packet (or  RX_NEXT) */
  uint32_t rxpdu_oo_pkts;       /* aggregated number of out-of-order rx pkts  (or RX_REORD) */
  uint32_t rxpdu_oo_bytes; /* aggregated amount of out-of-order rx bytes */
  uint32_t rxpdu_dd_pkts;  /* aggregated number of duplicated discarded packets */
  uint32_t rxpdu_dd_bytes; /* aggregated amount of discarded packets' bytes */
  uint32_t rxpdu_ro_count; /* this state variable indicates the COUNT value */
  uint32_t txsdu_pkts;     /* number of SDUs delivered */
  uint32_t txsdu_bytes;    /* number of bytes of SDUs delivered */
  uint32_t rxsdu_pkts;     /* number of SDUs received */
  uint32_t rxsdu_bytes;    /* number of bytes of SDUs received */
  uint32_t rnti;
  uint8_t  mode;               /* 0: PDCP AM, 1: PDCP UM, 2: PDCP TM */
  uint8_t  rbid;
} pdcp_radio_bearer_stats_t;

typedef struct {
  uint32_t len;
  pdcp_radio_bearer_stats_t* rb;

  uint16_t frame;
  uint8_t slot;
} pdcp_ind_msg_t;
```

Figure: One of the nine IE that a SM defines

- IE encoding and decoding is specified at compile time through C11 _Generic e.g., plain, ASN.1, Flatbuffers i.e., zero runtime cost overhead while offering great flexibility

```
#define pdcp_enc_ind_hdr(T,U) _Generic ((T), \
                              pdcp_enc_plain_t*: pdcp_enc_ind_hdr_plain , \
                              pdcp_enc_asn_t*: pdcp_enc_ind_hdr_asn, \
                              pdcp_enc_fb_t*: pdcp_enc_ind_hdr_fb, \
                              default:  pdcp_enc_ind_hdr_plain) (U)

#define pdcp_enc_ind_msg(T,U) _Generic ((T), \
                              pdcp_enc_plain_t*: pdcp_enc_ind_msg_plain , \
                              pdcp_enc_asn_t*: pdcp_enc_ind_msg_asn, \
                              pdcp_enc_fb_t*: pdcp_enc_ind_msg_fb, \
                              default:  pdcp_enc_ind_msg_plain) (U)
```

Figure: Encoding static polymorphism

3 Example of Indication msg: FlexRIC blocks

- ASIO: Asynchronous IO e.g., epoll
- EP: Endpoint e.g, SCTP connection
- AP: Application protocol e.g., encoding/decoding in ASN.1 or Flatbuffers
- MSG Handler e.g, event based logical block
- SM: Service Models i.e., loaded SMs
- iApps: Internal Apps e.g., write to a DB

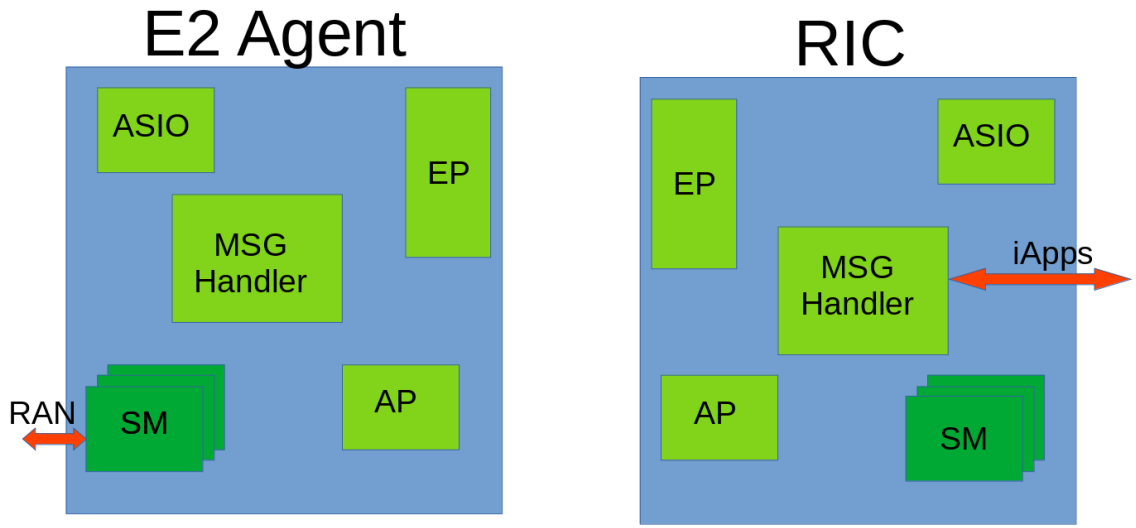


Figure: FlexRIC agent and RIC blocks

3 Example of Indication msg: Indication event on the agent

- Event is generated e.g., timeout
- The message handler calls the corresponding SM function e.g., on_indication
- The SM communicates with the RAN, fills the specific IE, encodes it and returns a byte array
- The message handler composes the e2ap_msg_t and calls the AP
- The AP encodes the e2ap_msg_t e.g., ASN.1 or FB
- The bytes are sent through the endpoint

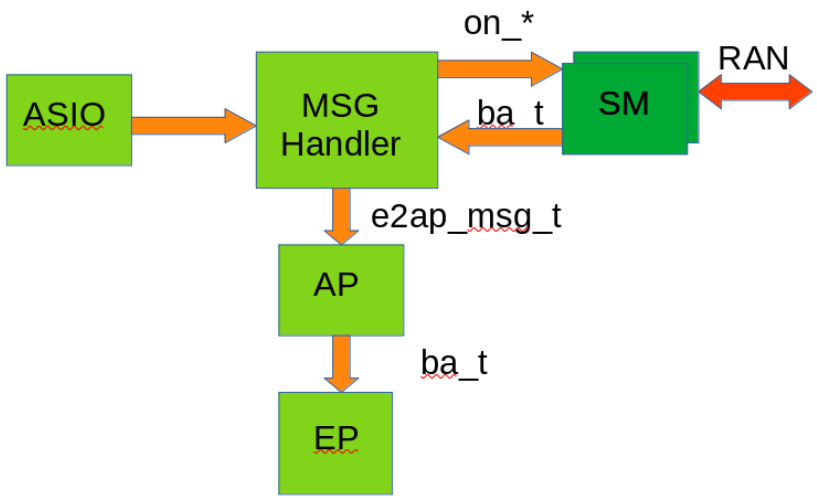


Figure: FlexRIC agent

3 Example of Indication msg: Indication event on the RIC

- A new event happened i.e., a new packet arrived
- The AP decodes the e2ap_msg_t
- The message handler calls the corresponding SM
- The message handler forwards the data from the SM to the subscribed iApps

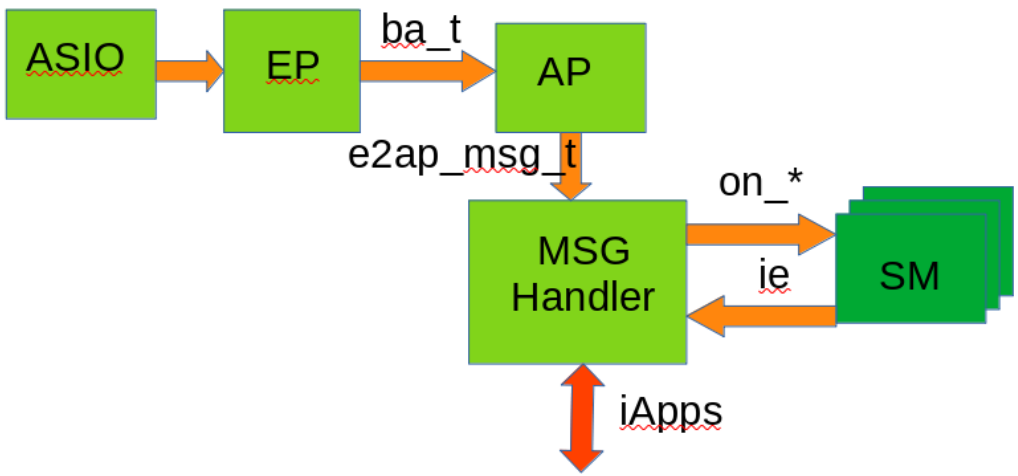


Figure: FlexRIC RIC

3 Example of Indication msg: Indication event Agent

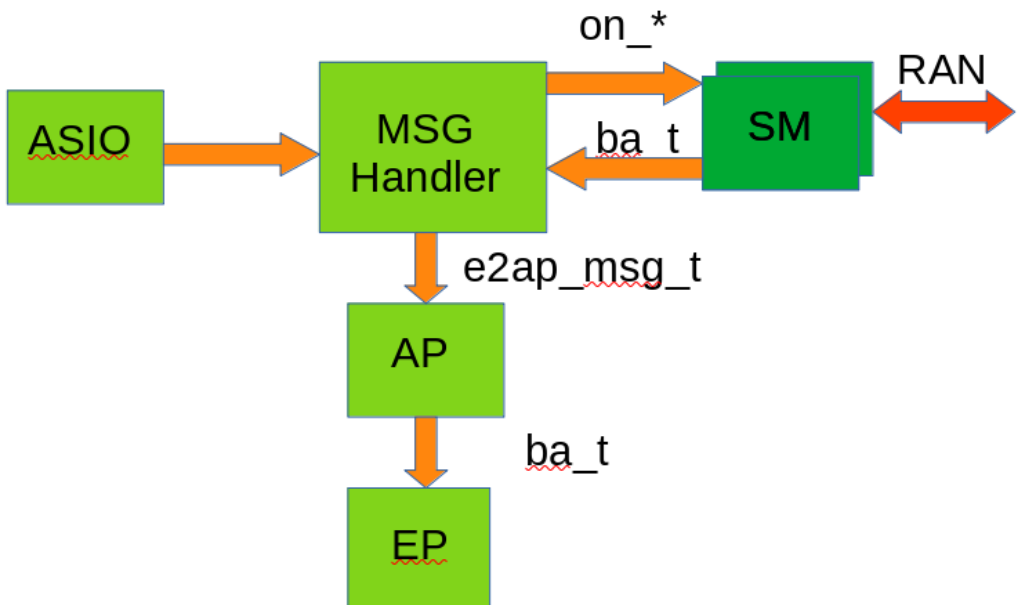

```
} else if(e.type == INDICATION_EVENT){

  sm_agent_t* sm = e.i_ev->sm;
  sm_ind_data_t data = sm->proc.on_indication(sm);

  ric_indication_t ind = generate_indication(ag, &data, e.i_ev);
  defer({ e2ap_free_indication(&ind); } );

  byte_array_t ba = e2ap_enc_indication_ag(&ag->ap, &ind);
  defer({ free_byte_array(ba); } );

  e2ap_send_bytes_agent(&ag->ep, ba);
```



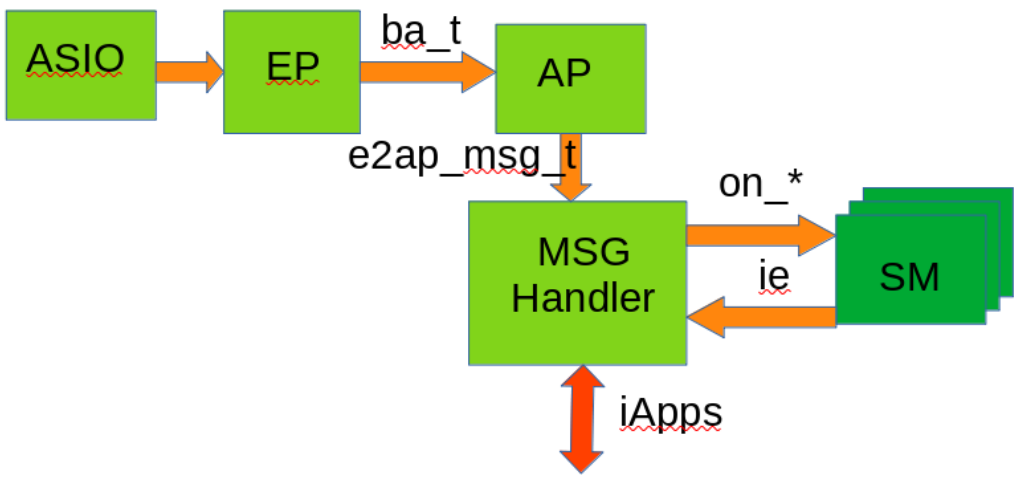
3 Example of Indication msg: Indication event RIC


```
if(net_pkt(ric, fd) == true){
  byte_array_t ba = e2ap_recv_msg_ric(&ric->ep);
  defer({free_byte_array(ba); } );

  e2ap_msg_t msg = e2ap_msg_dec_ric(&ric->ap, ba);
  defer({e2ap_msg_free_ric(&ric->ap, &msg); } );

  e2ap_msg_t ans = e2ap_msg_handle_ric(ric, &msg);
  defer({ e2ap_msg_free_ric(&ric->ap, &ans);} );

  if(ans.type != NONE_E2_MSG_TYPE ){
    byte_array_t ba_ans = e2ap_msg_enc_ric(&ric->ap, &ans);
    defer({free_byte_array(ba_ans); } );
    e2ap_send_bytes_ric(&ric->ep, ba_ans);
  }
```



```c
// E2 -> RIC
 e2ap_msg_t e2ap_handle_indication_ric(near_ric_t* ric, const e2ap_msg_t* msg)
{
  assert(ric != NULL);
  assert(msg != NULL);
  assert(msg->type == RIC_INDICATION);

  ric_indication_t const* ric_ind = &msg->u_msgs.ric_ind;

  const uint16_t ran_func_id = ric_ind->ric_id.ran_func_id;
  sm_ric_t* sm = sm_plugin_ric(&ric->plugin, ran_func_id);

  sm_ind_data_t data = {.ind_hdr = ric_ind->hdr.buf,
                        .len_hdr = ric_ind->hdr.len,
                        .ind_msg = ric_ind->msg.buf,
                        .len_msg = ric_ind->msg.len,
  };
  if(ric_ind->call_process_id != NULL){
    data.call_process_id = ric_ind->call_process_id->buf;
    data.len_cpid = ric_ind->call_process_id->len;
  }

  sm_rd_if_t d = sm->proc.on_indication(sm, &data);
  defer({ sm->alloc.free_ind_msg(&d); } );
  assert(d.type == MAC_STATS_V0 || d.type == RLC_STATS_V0 || d.type == PDCP_STATS_V0 );

  publish_ind_msg(ric, ran_func_id, &d);

  e2ap_msg_t ans = {.type = NONE_E2_MSG_TYPE };
  return ans;
}
```

4 Outline

4 Summary

- FlexRIC is O-RAN E2 standards compliant and closely follows the standard specifications
- FlexRIC achieves flexibility and extensability through the SM plugin system
- A SM needs to implement 5 procedures and 9 IEs for the agent and the RIC
- SM are not coupled to a encoding and decoding scheme. It's static polymorphism permits changing the scheme smoothly
- More details at https://dl.acm.org/doi/10.1145/3485983.3494870

Thank you!