

ns-O-RAN 프레임워크와 FlexRIC 연동 xApp 설계 및 구현

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Design and implementation of an xApp integrating FlexRIC with the ns-O-RAN Framework

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요약

본 연구는 Open Air Interface(OAI)의 near-RT RIC 플랫폼인 FlexRIC과 ns-3 시뮬레이터를 O-RAN 구조로 통합한 ns-O-RAN 프레임워크를 연동하여 해당 환경에서 동작하는 Key Performance Metric(KPM) 모니터링 기반 UE별 트래픽 이상치 탐지 xApp을 설계하고 구현하였다.

I. 서론

O-RAN은 개방형 인터페이스, 기능 분리, 가상화를 기반으로 RAN Intelligent Controller(RIC)를 도입하여, 지능형 무선망 제어를 핵심으로 하는 차세대 RAN 구조이다. O-RAN 구조에서 RIC는 제어 목적의 응답 시간 요구에 따라 Non-Real Time(RT) RIC와 Near-RT RIC으로 구분되며, 이 중 Near-RT RIC은 0.5-1 ms 수준의 짧은 지연 시간 내에서 무선망 제어를 담당한다. Near-RT RIC은 플랫폼 위에서 실행되는 xApp을 통해 제어 정책을 결정한다 [1].

본 논문에서 사용하는 Near-RT RIC 플랫폼인 FlexRIC은 ORAN-SC RIC에 비해 monolithic 구조로 구현되어 있어, use case 개발 및 구현이 용이하다. 현재, 이러한 초경량 구조를 기반으로 낮은 지연 시간을 제공할 수 있어, 소수의 고신뢰 클라이언트가 존재하는 5G 특화망과 같은 환경에서의 활용 가능성이 주목받고 있다 [2].

이에 본 논문에서는 FlexRIC과 ns-3를 O-RAN의 E2 인터페이스 및 소프트웨어 정의 기반 실제 네트워크와 연동한 ns-O-RAN 프레임워크를 연동한 구조를 제안한다. 해당 구조 위 FlexRIC 기반 시뮬레이션 환경에서 KPM 데이터를 활용한 xApp 개발이 가능함을 검증하였다.

II. 본론

1. 시스템 모델

1-A. ns-O-RAN

기존 ns-3 시뮬레이션은 셀 및 UE 수준의 데이터를 생성할 수 있었지만, O-RAN 구조는 지원하지 않았다. 이를 보완하기 위해 E2 인터페이스를 연동하여 소프트웨어 정의 기반의 네트워크로 확장한 ns-O-RAN 프레임워크를 구성하였다 [3].

ns-3 mmWave 모듈은 3GPP 기반 5G 셀룰러 네트워크의 중단 간 시뮬레이션을 수행하기 위해 설계되었다. 해당 모듈 안에 3GPP New Radio(NR) 프레임 구조와 numerology를 지원하도록 설계된 물리 계층(PHY) 및 MAC 계층 클래스는 최신 이동통신 기술과의 호환성을 보장한다. 또한, mmWave 모듈 MAC 계층에서는 carrier aggregation 및 다양한 스케줄링 정책을 지원한다. 또한, 이 모듈은 LTE 기지국과의 연결도 지원하며, 이를 통해 빠른 세컨더리 셀 핸드오버 및 채널 추적 기능도 제공한다 [4].

ns-O-RAN 프레임워크는 ns-3 mmWave 모듈에서 생성한 RAN 데이터를 e2sim E2 시뮬레이터를 통해 SCTP(Stream Control Transmission Protocol) 기반 패킷을 E2 인터페이스로 전달한다. 이를 통해 시나리오 내

의 각 gNB, eNB는 E2 Termination 객체를 통해 Near-RT RIC과 연결되어 FlexRIC RIC 플랫폼과 실시간 KPM 수집 및 제어 메시지 전달이 가능하다.

1-B. Near-RT RIC Platform - FlexRIC

FlexRIC은 OAI(Open Air Interface)의 Near-RT RIC 플랫폼으로 네트워크 API 방식 대신 Software Development Kit (SDK) 방식을 채택한다. 저지연 통신을 위해 FlexRIC의 xApp은 controller-internal application(iApp) 및 E42 프로토콜을 활용하여 RAN 기능과 직접 연동되며, SWIG를 인터페이스 컴파일러로 사용함으로써 다양한 프로그래밍 언어 기반의 xApp 개발을 지원한다. SDK 자체는 C 언어로 구현되었지만, SWIG를 통해 Python, C++, Java 등으로 확장이 가능하다 [2].

FlexRIC의 아키텍처는 크게 두 가지 핵심 모듈로 구성된다. 첫째, 에이전트 라이브러리는 기지국 내에 E2 호환 에이전트를 배치하고, 다양한 Radio Access Technology (RAT) 및 벤더에 중립적인 방식으로 동작한다. 둘째, 서버 라이브러리는 에이전트와의 연결을 관리하며, 네트워크 정보를 RNIB(Radio Network Information Base)에 저장하고, E2SM 구독(subscription)을 처리한다. 이러한 구독은 iApp을 통해 설정되며, iApp은 자체 제어 로직을 수행하거나, 외부 컨트롤러에서 실행 중인 xApp에 E2SM 기능을 제공하는 인터페이스 역할을 수행한다 [5].

1-C. 연동 구조

그림 1은 본 논문에서 제안하는 ns-O-RAN 프레임워크와 FlexRIC 간의 연동 구조를 나타낸다. Simulated RAN 측에는 ns-3 기반으로 구현된 4G LTE 또는 5G mmWave NetDevice가 위치하며, 이는 RRC, PDCP, RLC, MAC, PHY 계층을 포함한다. KPM Traces Generator를 통해 각 계층에서 RAN 측정치를 생성하고, 이를 기반으로 KPM 데이터를 구성한다. E2 Termination 모듈은 FlexRIC과의 연계를 담당하며, E2 인터페이스를 통해 E2AP 및 E2SM 메시지를 송수신함으로써 Near-RT RIC과의 상호작용을 수행한다.

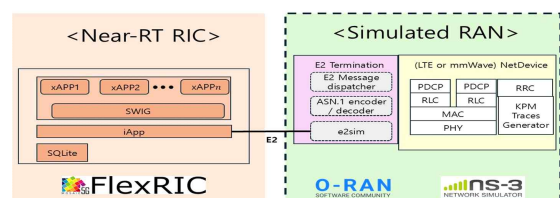


그림 1 . FlexRIC ns-O-RAN 연동 구조

2. xApp 설계 및 개발

2-A. 시나리오 및 데이터 정의

xApp 설계의 초기 단계에서는 ns-3 기반의 시뮬레이션 시나리오를 구성하여 KPM 데이터 생성 환경을 마련한다. 사용자는 SA(Stand Alone)/NSA(Non Stand Alone) 구조, 셀 및 단말 수, 이동성 모델, 채널 모델, 트래픽 패턴, 핸드오버 알고리즘 등 파라미터를 직접 설정하여 현실적인 무선 접속 네트워크를 시뮬레이션 할 수 있다.

2-B. FlexRIC xApp 소스코드 개발

xApp은 KPM Subscription 메시지를 생성하여 E2 노드에 전송하고, 이후 수신된 KPM Indication 메시지 형식에 따라 내용을 추출한다. 이 과정에서 KPM callback 함수를 직접 구현하였으며, 해당 함수는 메시지 수신 시 자동으로 호출되도록 구성된다. 함수 내부에서는 ASN.1 형식의 KPM 메시지를 수신하고, 각 UE별 측정 지표를 추출하여 로그로 출력하거나 분석을 위해 저장하는 기능을 수행한다.

3. xApp 결과 및 평가

xApp은 KPM callback 함수를 통해 E2 Termination으로부터 수신된 ASN.1 기반의 KPM 메시지를 디코딩하고, 각 단말(UE)별 metric 이름과 값을 파싱하여 로그로 출력한다. 그림 2-1은 Near-RT RIC과 E2 Termination과 xApp에서의 KPM 구독(subscription) 연결을 수립하는 절차 로그로 나타났다.

그림 2-2은 ns-3에서 생성된 KPM metric이 ASN.1 형식으로 인코딩되어 전송되는 로그 예시를 보여준다. 시뮬레이션에서 생성된 데이터는 Indication-Helper를 통해 O-RAN KPM 포맷에 맞게 매핑된다. O-RAN 구조 상 CU-CP, CU-UP, DU에 대응되는 측정값이다.

```
UE ID type = gNB, emf_ue_ngap_id = 219851796528
ran_ue_id = 0
--- KPM Indication Message Dump ---
kpmas_info_list_len: 23, meas_data_list_len: 23
Metric name: TB_TotNbrDLInitial.UEID | real_val: 212.000000
Metric name: TB_TotNbrDLInitial.UEID | real_val: 112.000000
Metric name: TB_TotNbrDLInitial.Qpsk.UEID | real_val: 39.000000
Metric name: TB_TotNbrDLInitial.64Qam.UEID | real_val: 0.000000
Metric name: TB_TotNbrDLInitial.64Qam.UEID | real_val: 173.000000
Metric name: QosFlow_PdcpPduVolumeDL_Filter.UEID = 45826.000000 **[ANOMALY DETECTED! Z-score: 2.34]**
Metric name: QosFlow_PdcpPduVolumeDL_Filter.UEID | real_val: 2.000000
Metric name: CARR_PDSCWCSDist.Bin1.UEID | real_val: 39.000000
Metric name: CARR_PDSCWCSDist.Bin2.UEID | real_val: 0.000000
Metric name: CARR_PDSCWCSDist.Bin3.UEID | real_val: 0.000000
Metric name: CARR_PDSCWCSDist.Bin4.UEID | real_val: 27.000000
Metric name: CARR_PDSCWCSDist.Bin5.UEID | real_val: 131.000000
Metric name: CARR_PDSCWCSDist.Bin6.UEID | real_val: 15.000000
Metric name: L1M-RS-SINR.Bin34.UEID | real_val: 0.000000
Metric name: L1M-RS-SINR.Bin58.UEID | real_val: 49.000000
Metric name: L1M-RS-SINR.Bin58.UEID | real_val: 0.000000
Metric name: L1M-RS-SINR.Bin79.UEID | real_val: 0.000000
Metric name: L1M-RS-SINR.Bin82.UEID | real_val: 154.000000
Metric name: L1M-RS-SINR.Bin94.UEID | real_val: 0.000000
Metric name: L1M-RS-SINR.Bin127.UEID | real_val: 9.000000
Metric name: DRB_BufferSize_Qos.UEID | real_val: 0.000000
Metric name: DRB_UETpdl.UEID | real_val: 1288.000000
```

그림 3. xApp KPM 모니터링 및 이상치 탐지 결과

다양한 RC와 Machine Learning Operations(MLOps)를 결합해 여러 use case에 적합한 xApp 개발 및 검증이 가능함을 시사한다.

III. 결론 및 향후 연구

본 논문에서는 ns-3 기반의 ns-O-RAN 프레임워크를 활용하여, 셀 및 UE 수준의 RAN 데이터를 생성하고, 이를 FlexRIC과 E2 인터페이스로 연계하는 구조를 제안하였다. 이를 통해 사용자 정의 xApp의 설계 및 동작 가능성을 시뮬레이션 환경에서 검증하였다.

FlexRIC은 경량화된 monolithic 구조로 구현되어 있어 빠른 개발과 배포가 가능하며, 저지연 특성 덕분에 5G 특화망 환경에 적합하다 [2]. 이후 제안한 구조를 기반으로 산업용 특화망에 적용 가능한 use case의 xApp 개발과 실시간 제어 연구로 확장할 수 있을 것으로 기대된다.

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```
%nearrt-ric
[UTL]: Setting the config -> file to /usr/local/etc/flexric/flexric.conf
[UTL]: Setting path to the shared libraries to /usr/local/lib/flexric/
NEAR-RT RIC IP Address = 127.0.0.1, PORT = 36421
NEAR-RT RIC: Initializing
NEAR-RT RIC: Loading SN ID = 142 with def = RRC_STATS_W0
NEAR-RT RIC: Loading SN ID = 148 with def = GTP_STATS_W0
NEAR-RT RIC: Loading SN ID = 149 with def = RRC_STATS_W0
NEAR-RT RIC: Loading SN ID = 143 with def = RRC_STATS_W0
NEAR-RT RIC: Loading SN ID = 146 with def = TC_STATS_W0
NEAR-RT RIC: Loading SN ID = 125 with def = CDR_STATS_W0
NEAR-RT RIC: Loading SN ID = 145 with def = SLIC_STATS_W0
NEAR-RT RIC: Loading SN ID = 3 with def = O-RAN-E2M-KPM
[App]: Initializing...
[App]: nearrt-ric IP Address = 127.0.0.1, PORT = 36422
NEAR-RT RIC: Initializing task runner with 3 threads
[E2AP]: E2 SETUP-REQUEST rx from PLMN 131.313 Mode ID 82083586 RAN type ngran_gNB
NEAR-RT RIC: Accepting RAN function ID 2 with def = O-RAN-E2M-KPM
[E2AP]: E2 SETUP-REQUEST rx from PLMN 131.313 Mode ID 82083586 RAN type ngran_gNB
NEAR-RT RIC: Accepting RAN function ID 3 with def = O-RAN-E2M-KPM
[E2AP]: E2 SETUP-REQUEST rx from PLMN 131.313 Mode ID 82083586 RAN type ngran_gNB
NEAR-RT RIC: Accepting RAN function ID 2 with def = O-RAN-E2M-KPM
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[E2AP]: E2 SETUP-REQUEST rx from PLMN 131.313 Mode ID 82083586 RAN type ngran_gNB
NEAR-RT RIC: Accepting RAN function ID 2 with def = O-RAN-E2M-KPM
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[E2AP]: E2 SETUP-REQUEST rx from PLMN 131.313 Mode ID 82083586 RAN type ngran_gNB
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[E2AP]: E2 SETUP-REQUEST
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