Utilizing OpenFlow, SDN and NFV in GPRS Core Network

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Abstract. Since GPRS introduction, mobile networks had gone a long way, however GPRS with its EDGE enhancement is still widely used, but the architecture proves to be outdated, complex and often hard to integrate with other technologies. With the introduction of new networking approaches such as SDN and NFV, many problems regarding GPRS emerge. In this paper we present a new architecture for delivery of GPRS service which uses modern approaches such as SDN and NFV. This architecture simplifies the whole network by moving mobile network intelligence to the SDN controller, while removing old, complex nodes such as SGSN and GGSN and mobile protocols such as GTP. This brings the network flexibility, programmability, service elasticity and vendor independency. No changes on the radio access network or the mobile terminal are required to deploy our simplified GPRS architecture, so backward compatibility and interoperability is ensured. Proposed architecture was implemented and tested with real radio access network and mobile terminal.

Keywords: 3GPP networks · GPRS · SDN · Software Defined Networking · NFV · Network Functions Virtualization · OpenFlow · Signaling and user data separation · Wireless networks · Cellular networks · PCU-ng · PCUng · ePCU · vGSN · GRE

1 Introduction

Enormous traffic growth in today's networks causes problems to both network operators and network equipment vendors. Operators are unable to cope with the increasing network complexity and expenses which growing network brings. Vendors on the other hand are forced to bring new more powerful products to the market to satisfy the operator's needs.

The traffic growth however does not correspond to the revenue growth, but as mentioned before, operators are forced to invest in the transport infrastructure which decreases the revenue even more. Therefore the infrastructure becomes very complex mix of different transport and access technologies, often managed by various Observation, Administration and Management (OAM) systems.

Emerging approaches as Software Defined Networking (SDN) [1] and Network Function Virtualization (NFV) [2] seem as a solution, because they try to address many problems of the current networking industry.

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Network appliances are expensive due to overall complexity, high performance and resiliency. Other problems include the vendor specific technologies and interfaces by which operators lock themselves to a single vendor, even they would wanted to choose every single networking element from a different network vendor.

Next problem is the time to market and flexibility of today's networks. Due to vendor specific technologies, proprietary or non-existent Application Programming Interfaces (APIs), introduction of new services has to be tightly consulted and cooperated with vendors, which increases the overall cost and time to market.

SDN and NFV promise to bring vendor independency, real-time analytics, more agile and flexible network management and quicker time to market. Mobile network equipment vendors have already released their first vision of SDN deployment in mobile networks, however they focus on the latest network technologies such as UMTS and LTE. There may be two reasons for this research aim. First is the better architectural fit of SDN and NFV to UMTS and LTE, because UMTS and LTE have split user-plane and control-plane transport over the network. Therefore it is more easy to use SDN in these networks, as SDN also builds on user and control plane separation. Second reason comes from the market. GPRS is an old technology and operators probably will not make serious investments to the GPRS based infrastructure in the future, therefore it does not make economic sense to invest into research of something, that might not generate enough revenue.

We, on the other hand, consider the SDN and NFV based GPRS network as interesting problem, as the 2G is still the most used mobile network due to its age, good coverage and penetration.

2 GPRS Network Basics

General Packet Radio Service (GPRS) is a technology which extends the standard Global System for Mobile Communication (GSM) network, so it can support packet switched data transport. It uses the same Radio Access Network (RAN) as the GSM does. RAN consists of Base Transceiver Station (BTS) and Base Station Controller (BSC). BTS is basically an antenna with modulation/demodulation and error correction circuitry. BSC controls a set of BTS and implements most of the logic of RAN. The GPRS capable BSC differs from GSM only BSC by an extra module called the Packet Control Unit (PCU). PCU splits incoming data from BTS into two types - packet switched traffic and circuit switched data/voice traffic.

Although RANs in GSM and GPRS network are fairly similar, the core network is totally different. GPRS adds totally new packet switched core network. It consists of Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). SGSN connects to the BSC/PCU by an interface or more precisely reference point called Gb. SGSN may be connected to multiple BSCs via Gb interface. SGSN is responsible for mobility and session management, ciphering, authentication and packet routing from given BSC to correct GGSN and the other way (from GGSN to correct BSC).

SGSN may be connected to more GGSNs. GGSN is basically an IP based router which connects to SGSN by Gn reference point from one side and to external packet switched networks (Internet, intranet, VPN, etc.) from the other side (Gi reference point). Gn reference point is based on GPRS tunneling protocol (GTP). GTP suite can be further divided into GPRS Tunneling Protocol – user plane (GTP-u) and GPRS Tunneling Protocol – control plane (GTP-c). GTP-u is used for user data transfer from SGSN to GGSN, where the GTP-u header is removed and a plain IP packet is sent towards for example Internet over Gi interface. GTP-c is used for signaling between SGSN and GGSN (e.g. PDP context creation, deletion and modification) and SGSN-SGSN signaling during inter SGSN procedures (e.g. inter SGSN routing area update) when mobile station moves from domain served by one SGSN to domain served by another SGSN. Both SGSN and GGSN have connections to SGSNs and GGSNs in other countries and networks, for roaming purposes. This reference point is named Gp.

Additionally to network nodes mentioned above, there are other support nodes in the GPRS network such as Home Location Registry (HLR), Visitor Location Registry (VLR), Mobile Switching Center (MSC) and Equipment Identity Registry (EIR). All subscription data of the user is stored in HLR. Network elements such as SGSN or MSC communicate with HLR to acquire user profile data (e.g. subscribed services, authentication info). VLR is usually collocated with MSC and stores the information of all users served by MSC. MSC is basically a call router in circuit switched part of the network. EIR is used for whitelisting or blacklisting of certain terminals, for example the stolen ones.

Two concepts, that are unique to 3GPP mobile networks is Packet Data Protocol Context (PDP context) and the Access Point Name (APN). PDP context is a logical connection between SGSN and GGSN through which user data is transferred. This connection is established during procedure called PDP context activation, by which the mobile station acquires an IP address (among other connection parameters).

APN is a simple string, which identifies the external network to which the mobile station wants to connect. It has to noted, that APN specifies at the same time the GGSN and the service which mobile station wants to use. One example of common APN is “internet”.

The typical scenario for GPRS mobile network consists of few procedures. First the mobile station has to connect to the network. This procedure is called the attach procedure. During this procedure the mobile network verifies the identity of the mobile station and assigns it a temporary identity for security purposes – Packet Temporary Mobile Station Identity (P-TMSI). Now the mobile station can send and receive SMS messages and calls. To send and receive packet switched data, it has to activate a PDP context. During this procedure, the mobile station specifies the service, to which it wants to connect (e.g. internet), QoS and other parameters. Network deduces the IP address of GGSN which provides requested service by a DNS resolution of APN and assigns an IP address to the mobile station. From this moment, the mobile station is able to communicate with external networks. All the user data traverses BTS, BSC/PCU, SGSN, GGSN and then finally leaves the mobile network. It has to be noted that in GPRS architecture, the signaling information (between BSC/PCU and SGSN) and user plane information are transported together over GPRS-Network Service (GPRS-NS) layer.

Later an enhancement of GPRS architecture came, called Enhanced Data rates for GPRS Evolution (EDGE), which brought higher order modulation and new coding schemes on the radio interface towards the mobile terminal. Changes required for EDGE deployment were mainly made in the radio access network.

Next generations of mobile networks such as Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE) will not be explained in this paper (Fig. 1.), detailed network architecture, principles and protocols can be found in 3GPP standards [3] [4] [5].

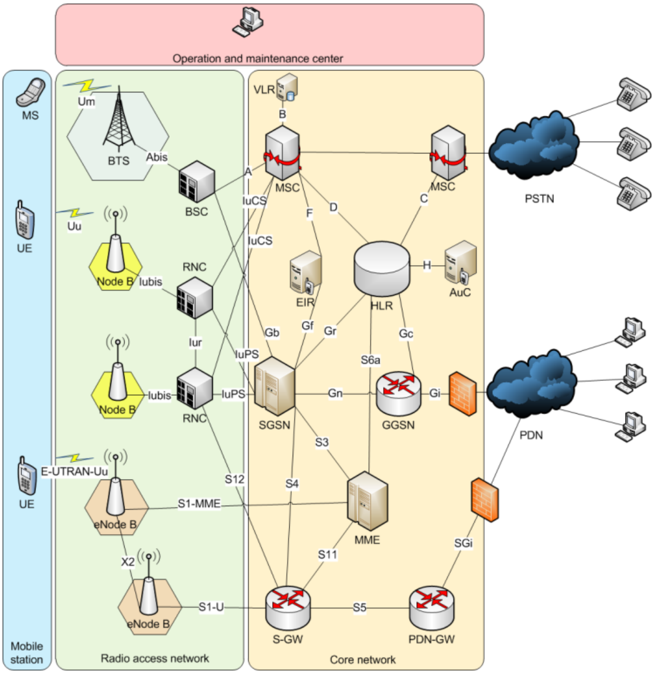

Fig. 1. GSM/GPRS/UMTS/LTE network with both packet switched and circuit switched parts of the network

2.1 Software Defined Network and Network Function Virtualization

Computer networks, even if highly distributed, combined both data and control plane from the start. Introduction of new services and features was slow and vendor dependent.

In general the term Software Defined Networking (SDN) stands for more programmable way of controlling the network behavior. It also includes forwarding (user plane) and control plane decoupling, so the control plane (network intelligence) is logically centralized in one single place [6].

SDN architecture can be generalized to three basic components: forwarder, controller, network/business applications.

In addition to mentioned three entities, reference points (interfaces) can be defined: northbound interface, southbound interface, westbound interface, eastbound interface.

SDN controller logically centralizes the network's intelligence and controls the forwarding plane by southbound interface. Moreover forwarding plane can be queried for statistical information or notifications can be received through this interface. The northbound interface of SDN controller is used for communication with various external networks and business applications which can query controller for information, for example network performance, topology, or request from controller some kind of action such as policing. Eastbound and westbound interfaces are used mainly in inter-controller communication, for example when each controller is located in different domain and they want to cooperate for example in path computation. It is worth noting, that all interfaces should be well standardized and information exchanged over these interfaces should be well abstracted to avoid vendor lock-in and emphasize fast adoption [7] [8].

All in all SDN promises decrease of overall costs of the network devices, increase of flexibility and easier management. By the control and forwarding plane decoupling, each plane can evolve independently while keeping compatibility through well-defined network APIs. As the area is very wide, many standardization bodies and vendors came up with their own, sometimes even open approaches.

Network Functions Virtualization (NFV) is ETSI's initiative to move specialized network functions from special and expensive hardware to general purpose x86/x64 computing architecture. It addresses networking in general, so numerous different use cases are proposed, for example there are use cases which consider virtualization of the Customer Premises Equipment (CPE), so only the necessary part of it is really present at the customer's place. CPEs can be therefore smaller, cheaper, more energy efficient and also more controlled and managed by the network operator. Other use cases include virtual base stations, IMS core, CDN networks and mobile network core. NFV is a complementary approach to SDN. Actually NFV and SND can benefit from each other. As the workgroup itself is very new, there is no exhaustive information available at the time being.

2.2 OpenFlow

As we built our new architecture on OpenFlow protocol, it is appropriate to introduce the OpenFlow protocol. It is the currently most popular SDN approach widely accepted in the academic community and the vendor community. OpenFlow splits the network into control plane and forwarding plane. Forwarding plane implemented by OpenFlow switches is managed by OpenFlow controller which is logically centralized.

OpenFlow switch behaves according to flow table, which consist of match criteria, actions and counters ordered in flow entries. Match criteria is a set of different protocol header fields and packets are compared against this criteria. Supported match criteria, actions and counters vary based on the OpenFlow version the switch and controller are compliant to. If the packet (flow) is matched, statistics are updated and corresponding action is executed. If packet does not match any entry in the flow table, forwarder can either drop the packet or send packet to the controller for further processing. OpenFlow protocol is used to add, delete and modify the flow table inside the OpenFlow Switch. A different protocol, OF-Config based on NetConf/Yang, was added to query OpenFlow switch capabilities and change parameters of the device. The most widespread version is 1.0 released in December 2009. Next versions of the switch specification and protocol added support for multiple flow tables, group flow table to manage multiple flows, IPv6 support, MPLS matching, meter support for QoS and support for multiple controllers. Due to its simplicity, OpenFlow was quickly adopted by the academic community and the commercial community. At the time being first commercial products are being introduced. Moreover many open source OpenFlow solutions exist [6].

3 Related Work

Mobile network operators and vendors are also trying to adopt the SDN philosophy to their use cases and benefit from the control and user plane decoupling, network programmability, scalability and reduction of expenses. However since the SDN approach is relatively new, no commercial deployment of SDN based mobile network was done yet.

For example Alcatel-Lucent/Bell-Labs proposed a concept of vertical forwarding. Vertical forwarding described by their approach basically means tunneling of data through the network [9]. Alcatel-Lucent sees the main disadvantage of carrier network in numerous of gateway nodes (mobility, security, etc.). These gateway nodes have often vendor specific interface and use specific signalization protocols as they execute specific functionality. As they pose a single point of failure, they must be extremely resilient which increases the cost of the equipment. To deal with these drawbacks, control plane and forwarding plane split is proposed in this approach. Intelligence and control of all gateways should be logically moved to the controller and forwarding plane should be realized on simple hardware. By using single controller of all gateways, network can react on failure of the network appliance and reroute traffic to the healthy nodes, without using special inter-gateway communication protocols.

Moreover control and data plane can evolve separately, upgrades and new protocols can be introduced separately for each element, where the change on one element will not affect the other.

Ericsson on the other hand proposed a GPRS Tunneling Protocol (GTP) extension for the OpenFlow protocol for Evolved Packet Core (EPC) [10]. This approach has been experimentally tested, however on UMTS architecture, where instead of MME, S-GW and P-GW a combination of SGSN and GGSN was used. It is worth noting that Ericsson has also patented this approach both in LTE/EPC [11] and in UMTS [12]. Authors of the paper argue, that EPC (and other 3GPP based mobile architectures) relies on two forms of routing, which are not coordinated, but on the other hand rely on each other. The first layer is the IP routing and second is GTP routing based on Tunnel Endpoint Identifiers (TEID) in GTP header. Coordination can be achieved, when the IP routing logic will be collocated with the GTP routing logic (MME, P-GW, S-GW, etc.).

Huawei with its MobileFlow architecture is defining an area of Software Defined Mobile Networks (SDMN) [13]. Architecture consists of MobileFlow Controller (MFC) and MobileFlow Forwarding Engines (MFFE). MFFE are somehow similar to OpenFlow forwarders, but little more feature rich (but still simpler than traditional network nodes). MFFEs are capable of for example GTP encapsulation, charging and policing. They implement the MobileFlow protocol on the Smf reference point. The control plane is similarly to OpenFlow centralized around MobileFlow Controller. MobileFlow uses MobileFlow protocol as a southbound protocol to communicate with MFFE. Controller is capable of communication with similar controllers via east-west interface, northbound interface is used to communicate with network applications. These applications can include EPC entities functionality (e.g. MME) or novel network applications. MobileFlow preserves the interoperability with existing UEs, therefore the changes in core network are transparent. Huawei successfully proved and tested their novel architecture by implementing UMTS and LTE network with real eNodeB and other simulated nodes.

All in all, it is evident that network vendors consider SDN as viable approach. However the market seems to be very conservative and the real commercial solutions are probably just yet to come.

4 Novel SDN and NFV Enabled GPRS Architecture

In traditional GPRS architecture, signaling and user plane data is transported together (between BSC/PCU and SGSN). For efficient use of SDN and NFV in the GPRS network, we have to separate these two types of information. This is desirably done as close to the radio access network as possible.

In our new GPRS architecture, we deploy a GPRS aware OpenFlow switch, which separates signaling and user plane data so streams of signaling only and user plane only messages are available. We call this new network element PCU for next generation networks (PCU-ng). The GPRS signaling is routed to the integrated GPRS control element called vGSN and the stream of user plane data is encapsulated into Generic Routing Encapsulation (GRE) protocol and routed to desired point (e.g. Internet).

vGSN combines functionalities of SGSN and GGSN from the classic GPRS architecture, mainly mobility management and security functions. For session management functions we use OpenFlow based SDN controller. SDN controller and vGSN communicate in order to setup, modify or teardown the sessions (PDP contexts) of the mobile stations. The advantage of splitting mobility and session management to two separated nodes is that architecture remains highly extensible for adding new mobility management nodes for future access technologies to the network with no or minimal impact on existing ones.

The session management in our architecture differs from the GPRS session management. We have substituted the GTP-u protocol, which is used only in mobile networks for something more common – GRE protocol (Generic Routing Encapsulation). Also tunnel management procedures have changed. Since we don't have a standalone SGSN and GGSN, there is no need for GTP-c signaling. The transport core network can easily be implemented by cheap OpenFlow GRE enabled switches. GRE tunnels are being created, modified or teardown by the SDN controller according to requests from vGSN. This is also an advantage since in classic GPRS architecture, a PDP context could be terminated only on GGSN. As our architecture does not have any GGSN node, we can terminate GRE tunnels anywhere we want, which enables further traffic flow optimization (e.g. offload Internet traffic from the network as soon as possible).

After the PDP context activation request from the mobile station, the vGSN informs the controller of the desired GRE tunnel/PDP context parameters. These include mainly the endpoint of the GRE tunnel deduced from the APN, the beginning of the tunnel given by source PCU-ng and QoS. SDN controller installs this GRE tunnel according to resources in the network and the user plane data can flow to and from the desired destination from this moment.

It has to be noted that the signaling messages towards mobile station remain the same, so no changes in protocol stack in BSC or mobile station is required.

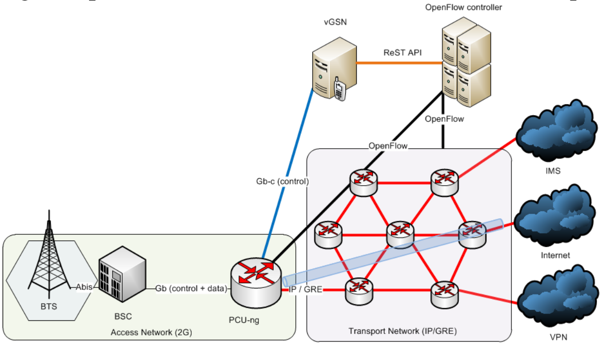

Fig. 2. New SDN/NFV based GPRS architecture

The PCU-ng operates as follows. It considers Service Access Point Identifiers (SAPI) 3, 5, 9, 11 in the GPRS-Logical Link Control (GPRS-LLC) layer header as the user data and the others as signaling. It has to be noted that signaling also includes GPRS transported SMS messages and Tunelling of Messages envelopes (TOM), but this can be handled as signaling in the vGSN. To match the LLC-SAPI field, OpenFlow protocol had to be extended to match all underlying protocols and fields. First the standard IP and UDP protocols are matched. Certain UDP port number tuples are considered as a transport for GPRS – Network Service layer (GPRS-NS), this is of course configurable. Inside GPRS-NS the Packed Data Unit (PDU) type field is matched. This field can either be GPRS-NS keepalive (NS_ALIVE/NS_ALIVE_ACK), which is forwarded to vGSN or other (NS_UNIDATA) which requires further processing. At GPRS-NS layer PCU-ng also processes the BSSGP Virtual Connection ID (BVCI) which identifies a virtual connection between BSC/PCU and SGSN. If the packet is NS_UNIDATA type, PCU-ng proceeds to further processing of Base Stations Subsystem GPRS Protocol (BSSGP) layer. First important field is the BSSGP PDU type, which can be again a BSSGP level signaling (e.g. FLOW-CONTROL-BVC, FLOW-CONTROL-BVC-ACK), or other types of messages (DL-UNIDATA, UL-UNIDATA). If other types of messages are matched, PCU-ng advances to analyzing the other fields such as Temporary Logical Level Identity (TLLI), which identifies the Mobile station. Last layer which is analyzed is the GPRS-Logical Link Layer (GPRS-LLC). Here only the Service Access Point Identifier is analyzed. Based on the value of this field, the PCU-ng decides whether the packet is a user plane message (SAPI=3, 5, 9, 11) or other (signaling, SMS, TOM).

5 Experimental Setup and Results

We implemented our solution from freely available open-source components. Our radio access network consists of open source hardware-based BTS. It provides one quad band GSM/GPRS TRX with an IP/Ethernet connection to the core network (Gb over IP). Base station is EDGE capable, however support in the PCU was not implemented yet. This missing support affects only the radio access network part and it is not important for our test setup. An open-source GPRS PCU (osmo-pcu [14]) resides on this hardware and connects to GPRS enabled OpenFlow forwarder – PCU-ng. This element implements custom GPRS OpenFlow actions (push/pop of BSSGP, GPRS-LLC and SNDC protocol headers) and custom GPRS match criteria (matching of selected information elements in GPRS related protocol headers) as enablers for the user and control plane separation. Our GPRS access controller module – vGSN is also based on open-source components, mainly osmo-sgsn [15] and open-ggsn [16]. vGSN combines the network intelligence of both nodes, while the data-path (user-plane processing) is moved to PCU-ng and other forwarders in the network.

OpenFlow components are based on ofsoftswitch (CPqD) [17] forwarder and RYU controller [18], both OpenFlow 1.3 compliant [19]. We cloned both project repositories and we are modifying the sources with a final goal to get GPRS support merged into project mainlines.

At the time being we are able to split the signaling and user plane data by PCU-ng and forward them to required locations. User plane data is moreover encapsulated into GRE as mentioned before. Extensive GRE tunnel management is in the development phase. Regarding the mobility management, as our current setup routes mobility and authentication messages towards circuit switched part of core network, we are not dealing with them right now on vGSN. However after the tunnel management work is done, the setup will be change to reflect the real topology and scenarios including the mobility management with multiple BTS/BSC.

6 Conclusion

All in all we have significantly simplified the GPRS architecture from the point of overall infrastructure, by replacing complicated SGSN and GGSN nodes by extensible vGSN and SDN controller nodes, which can run on general x86/x64 architecture (NFV). In the legacy architecture, each PDP context had to be terminated only on GGSN node. In our architecture, PDP context can lead to any of the OpenFlow forwarders, which will strip off the GRE header and send user data to the external network. This enables offloading heavy traffic destined for the Internet from the core network as soon as possible. Next we have substituted the GTP protocol, which is only used in mobile networks for something very common and simple – GRE protocol (Generic Routing Encapsulation). The architecture is an enabler for seamless mobility as it has a single session manager (SDN controller) which will bring a single, not changing IP address for mobile devices changing their access networks. Moreover the architecture enables extensibility for future access networks.

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