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THE IMPACT OF MOBILE NETWORK SETTINGS ON THE POWER CONSUMPTION OF VEHICLE REMOTE CONTROL UNITS

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The article is devoted to the study of the influence of mobile network settings on the energy consumption of electronic car control units. Signal quality and mobile network coverage are also important for both users and automotive devices that use real-time information from the network using cloud technologies to transmit, process and store data. For the quality of service measurements, Communications Regulatory Authority uses just HTTP data transmission (receipt) speed rate values in the operators' UMTS (3G) networks (as CRA stated in annual report). But speed is not everything as many consumers in the industry are experiencing recently. In addition, improvements now also revolve about reducing the signaling load incurred when a radio bearer is established, modified or released. Another area for improvements is the signaling overhead on the air interface when little data is transferred as it consumes resources and causes battery drain from the mobile phone's point of view.

The authors focused on the UMTS (the Universal Mobile Telecommunications System) 3G network, which is among the most popular 3G mobile communication technologies. We explore the RRC state machine of large cellular networks which operate in Lithuania.

Note that in UMTS network, the centralized core network (CN) is responsible for ensuring switching and routing for the end users traffic. All Network management functions and required databases are also implemented in core network. The core network domain is further divided into sub categories: serving network domain, home network domain and the transit network domain. It consists of two kinds of General Packet Radio Service (GPRS) Support Nodes (GSNs), in 3GPP named as Gateway GSN (GGSN) and Serving GSN (SGSN) (Figure 1). SGSN is the central node of the packet switched (PS) domain. It provides for routing functionality and interacts with databases (like Home Location Register (HLR)) and manages many Radio Network Controllers (RNCs).

So the authors were researching the RRC machines of Lithuanian cellular operators' networks. The purpose of those experiments was to identify which network could provide a best user internet browsing experience, best user equipment battery consumption feature and best radio network resource utilization scheme. We can state, that comparing all these partitions, Operator2 has the optimal configuration for user experience, UE device battery consumption and network resource utilization of RRC state machine point of view.

Keywords: car, mobile network, electronic unit, mobile telecommunication system, network management.

Introduction

Modern technologies allow to monitor traffic jams due to the signals of the drivers' and passengers' mobile phones, radio signals influence energy consumption of electronic control units.

Signal quality and mobile network coverage are also important for both users and automotive devices that use real-time information from the network using cloud technologies to transmit, process and store data.

Cellular data networks in Lithuania are growing very rapidly despite the appearance of the new network technologies on the market. As when writing this paper, 262k users were using UMTS high speed data transfers and this is 24.4% more than the last year [1]. All mobile network providers in Lithuania can offer high data transfer rates for various user needs and the applications they use. For the quality of service measurements, Communications Regulatory Authority uses just HTTP data transmission (receipt) speed rate values in the operators' UMTS (3G) networks (as CRA stated in annual report). But speed is not everything as many consumers in the industry have been experiencing recently. In addition, improvements now also revolve about reducing the signalling load incurred [6] when a radio bearer is established, modified or released. Another area for improvements is the signalling overhead on the air interface when little data is transferred as it consumes resources and causes battery drain from the mobile phone's point of view [7]. Battery lifetime is a big challenge with smart phones.In this paper, we focus on the UMTS (the Universal Mobile Telecommunications System) 3G network, which is among the most popular 3G mobile communication technologies. We explore the RRC state machine of large cellular networks which operate in Lithuania.

Overview of UMTS

In this section we provide a short background of UMTS network for further discussions in this paper.

The UMTS network consists of three major parts or subsystems: User Equipments (UE), UMTS Terrestrial Radio Access Network (UTRAN), and the Core Network (CN) (refer Figure 1). UEs are mobile handsets used by the end users. The UTRAN is for connecting the end user equipment (UE) with the core network (CN). It consists of two components: base stations, which by 3GPP are called NodeBs, and Radio Network Controllers (RNC), which control multiple NodeBs. Such UTRAN features as packet scheduling, radio resource control and handover control are implemented at the RNC node [2].

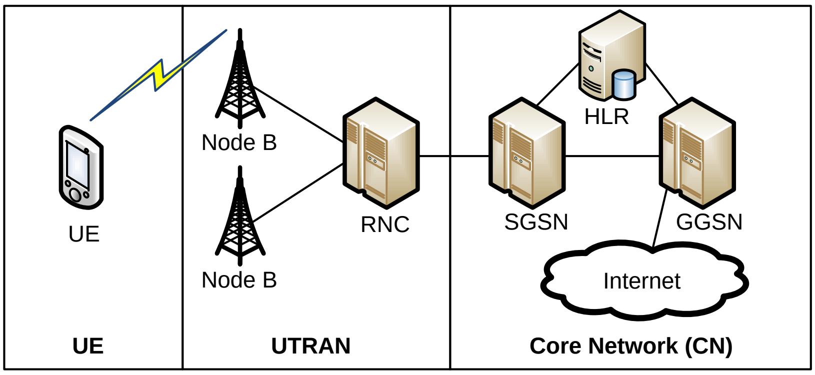

Fig. 1 –Simplified UMTS network architecture

In UMTS network, the centralized core network (CN) is responsible for ensuring switching and routing for the end users traffic. All Network management functions and the required databases are also implemented in the core network. The core network domain is further divided into sub categories: serving network domain, home network domain and the transit network domain. It consists of two kinds of General Packet Radio Service (GPRS) Support Nodes (GSNs), in 3GPP named as Gateway GSN (GGSN) and Serving GSN (SGSN) (Figure 1). SGSN is the central node of the packet switched (PS) domain. It provides routing functionality and interacts with databases (like Home Location Register (HLR)) and manages many Radio Network Controllers (RNCs). GGSN provides the interconnection of UMTS network with other Packet Data Networks (PDNs) like the Internet. In particular the GGSN (Gateway GPRS Support Node) within the CN serves as a gateway hiding UMTS internal infrastructures from the external network.

The RRC State Machine

User specific packet scheduling is mainly responsible for the utilization of the Radio Resource Control (RRC) states, transport channels and their bit rates according to traffic pattern. The packet scheduling is done by RNC in UMTS network. In packet scheduling, NodeB provides for the air interface load measurements and the UE provides the uplink traffic volume measurements to the RNC. In the UMTS, the radio resource refers to WCDMA codes that are potential bottleneck resources of the network. To efficiently utilize the limited radio resources, the UMTS radio resource control (RRC) protocol introduces a state machine associated with each UE. There are typically three RRC states and those states are described bellow [3, 4].

RRC state IDLE. This is the default state when a UE is turned on. The UE has not yet established an RRC connection with the RNC and no radio resource is allocated to UE. The UE cannot transfer any user data and just network control data is allowed.

RRC state CELL PCH. Even while in CELL FACH state, the mobile device requires a considerable amount of power to listen to the forward access channel (CELL FACH) despite its minimal activity. Because of noticeable delay when resuming data transmission from the idle state, one further state have been specified which are between Idle and CELL FACH. In CELL PCH state, the mobile needs to periodically listen to the paging channel while the logical connection the radio network and the device remain in place. If there is renewed activity, the connection can be quickly resumed.

RRC state CELL FACH. The RRC connection is established but there is no dedicated channel allocated to a UE. The UE can only transmit user data through shared low-speed channels that are typically less than 15 kbps. Henceforth CELL FACH is referred as FACH from this point in this paper. FACH is designed for applications requiring very low data throughput rate. It consumes much less radio resources than the DCH UE state.

RRC state CELL DCH. The RRC connection is established and a UE is usually allocated dedicated transport channels in both downlink (DL, RNC to UE) and uplink (UL, UE to RNC) directions.

This state allows a UE to fully utilize radio resources for user data transmission. Henceforth CELL DCH is referred as DCH in from this point this paper. At DCH state a UE can access HSDPA/HSUPA (High Speed Downlink/Uplink Packet Access) mode, if supported by the ISP network infrastructure. For HSDPA, the high speed transport channel is not dedicated, but shared by a limited number of users [3]. Even more, when a large number of UEs are in DCH state, the radio resources may be all exhausted due to the lack of channelization codes in the cell. In this case scenario some of the UEs have to use low-speed shared channels although their RRC states are still DCH mode [3].

The RRC states impact a UE's energy consumption significantly. To utilize the limited radio resources, RRC state machine determines radio resource usage affecting device energy consumption and user experience. An UE can be in one of three states, each with different amount of allocated radio resources. The transitions between states also have significant impact on the UMTS system. Frequent state promotions (allocation of the resources) could yield long delays for the UE and additional processing power for the UTRAN nodes [5]. Resource releases, or state demotions, are controlled by inactivity timers, which affect radio resource usage and UE energy consumption [5].

There are two types of state transitions in the RRC state machine. State promotions, including PCH→FACH, FACH→DCH, and PCH→DCH, switch from a state with lower radio resource and UE energy utilization to a state which consumes more radio resources and UE energy. State demotions are DCH→FACH and FACH→PCH. Depending on the starting state, a state promotion is triggered by user data transmission activity, if the UE is at IDLE, or the per-UE queue size, called Radio Link Controller (RLC) buffer size, if the UE is at FACH state [3]. The state demotions are triggered by two inactivity timers maintained by the RNC.

Promotions need more work to be done than demotions. In particular, a state promotion gives a long latency of up to couple of seconds during which a lot of control messages are exchanged between the UE and the RNC for resource allocation. State promotions increase the management overhead at the RNC and degrade user experience [2], especially for short data transfers.

Figures 2 and 3 shows possible state machine models for UMTS networks. The difference of state transitions gives a problem to investigate for the optimal state machine configuration for better balance of radio resource utilization, performance and user experience.

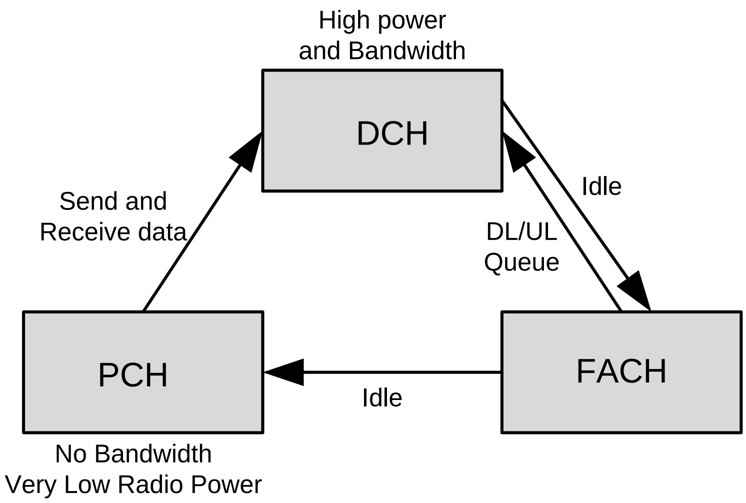

Fig. 2 – The RRC state machine model 1

Measuring RRC state parameters

There are three public mobile telephone communication operators, operating in the Republic of Lithuania with their own network infrastructure [1]. All operators have implemented 3G technologies and have a significant number of consumers generating revenue for mobile data transmissions. In this paper, we name these operators as Operator1, Operator2, and Operator3 to avoid misunderstanding in terms of commercial dependencies. The design of the RRC state machine is ad-hoc with statically preconfigured parameters [2] and these network settings are individual for each cellular ISP. In this paper we study the design using real cellular traces of Lithuanian cellular ISPs and analyze the effect on important factors from both the network operator's perspective (radio resource usage efficiency) and from end-user's perspective, namely mobile device energy consumption and performance of applications.

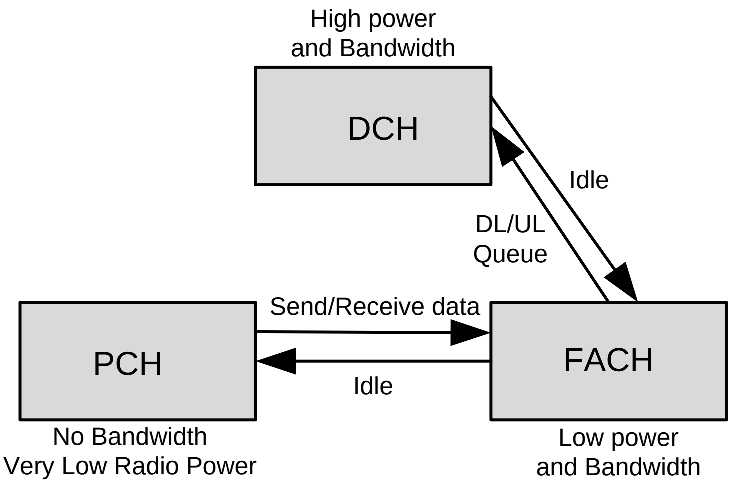

Fig. 3 – The RRC state machine model 2

According to organizations of market research (for e.g. Gartner), mobile email and other services, related on it, are top data generating applications used in smart phones worldwide. Power consumption measurements were done receiving one email message 10 kB of size and recording the UE power consumption and the RRC state during the download. The phone was connected as "always on" to the internet, which means it was in PCH state at least.

We have used Nokia mobile phone for our measurements. All unneeded services (applications) and features, such as Bluetooth, were turned off during the measurements. To measure the energy consumption as precisely as possible, we connected the phone to an external power supply with multimeter and phone battery was not used to avoid any inaccuracies of battery. Network state measurements were done with Nokia Energy Profiler 1.2 software and recorded to the phones internal memory. All data were collected in one location avoiding power from NodeB fluctuations. Also all measurements were repeated several times in different months of the year. We noticed that cellular operators' network settings remained the same during our measurement period. Comparing received power (Rx) at the UE, we can conclude that Operator's1 NodeB was closest to our location and Operator's3 – furthest (refer Table 1).

Table 1

Summarization of RRC state parameters of operators

Mobile ISP / Measurements	Operator1	Operator2	Operator3
Promotion power, [mW]	none	none	none
PCH -> FACH	600	n/a	556
PCH -> DCH	n/a	868	n/a
FACH -> DCH	406	n/a	560
Demotion power, [mW]	none	none	none
DCH -> FACH	618	565	647
FACH -> PCH	388	302	469
Duration in state, [s]	none	none	none
DCH	14,25	6,25	7,25
FACH (promotion)	1,75	0	1,75
FACH (demotion)	10,5	33,00	7,25
Average Rx level,[dBm]	-37	-60	-64
Average Tx level,[dBm]	-48	-37	-22

In Figure 4, Operator's1 RRC state transitions are displayed when data is transferred (Figure 5). From the graphs it is seen, that RRC state machine model 2 is used.

Only Operator2 uses RRC state machine model 1 (Figure 2), which lets UE overpass state FACH and use all the benefits of DCH. This method lets to improve user internet browsing experience and reduce UE's battery power consumption.

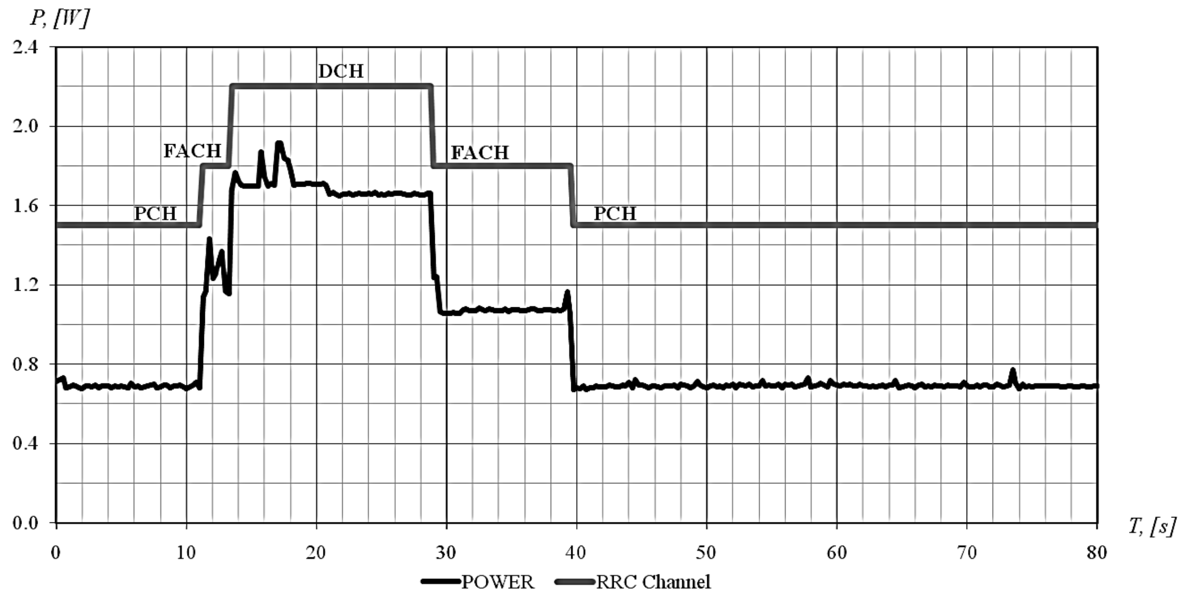

Fig. 4 – Operator's1 RRC states and consumed power

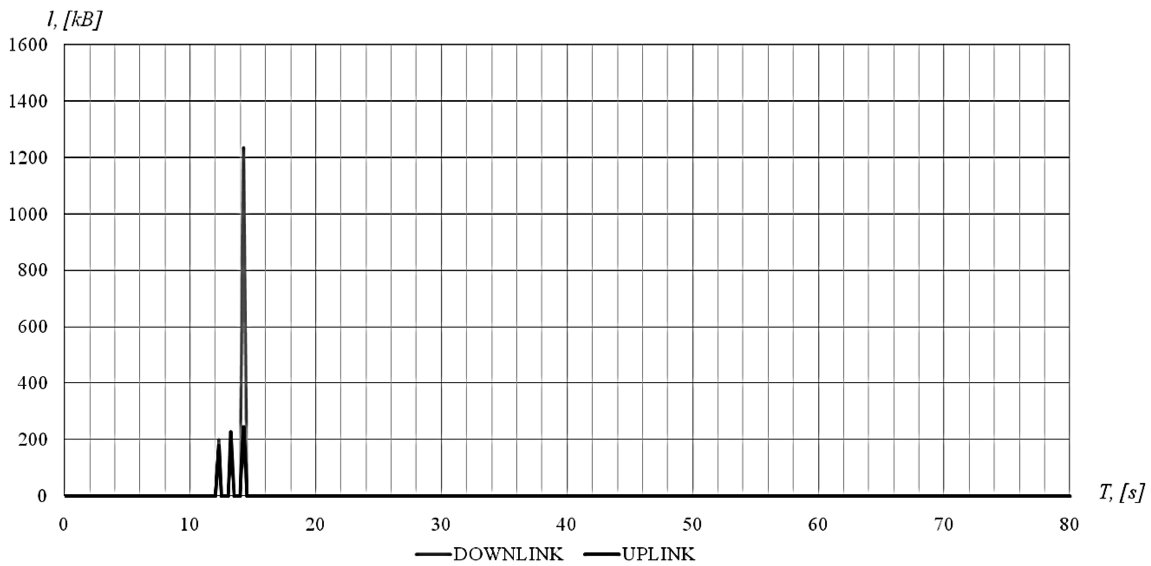

Fig. 5 – Data download from Operator's1 network to UE

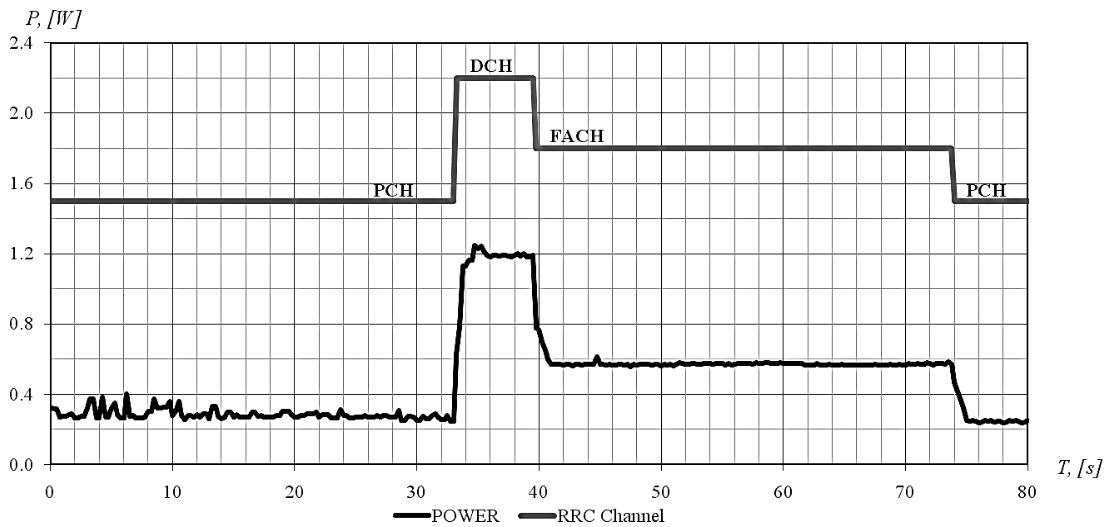

Fig. 6 – Operator's2 RRC states and consumed power

Operator3 uses the RRC state machine model 2 as Operator1 and transition time from FACH to DCH match.

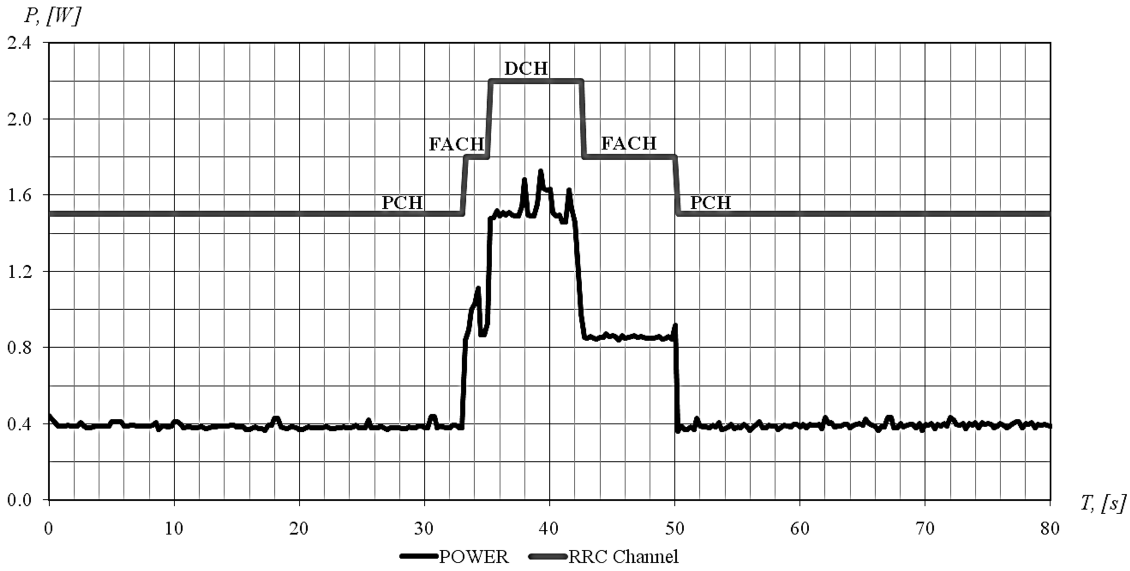

Fig. 7 – Operator's3 RRC states and consumed power

Comparing RRC state machines

Comparing RRC state machines of cellular operators in terms of user experience, Operator1 is the best. The network has the longest DCH state (almost 15 seconds), which lets users comfortably browsing the internet without waiting FACH→DCH promotion time, which is almost 2 seconds (refer Table 1 and Figure 7). Also, UEs are left quite significant time in demoted FACH state, which lets quickly resume to DCH. The longest demoted FACH state has Operator2. Operator2 uses first RRC state transition model (refer Figure 1), which lets to improve user experience in internet browsing activity.

Comparing UE's battery consumption when user is in different mobile networks, UE in Operator1 network consumes energy the most (despite it is closest to NodeB) and in Operator's3 network – the least. The difference between energy consumption in Operator's1 and Operator's3 networks is quite significant (about 50%) (refer Figure 8, 9). So theoretically, Operator's1 network drains UE's battery 2 times faster than Operator's3 network. And it is obvious, because duration time in DCH state is also about 50% longer comparing Operator's1 and Operator's2 networks.

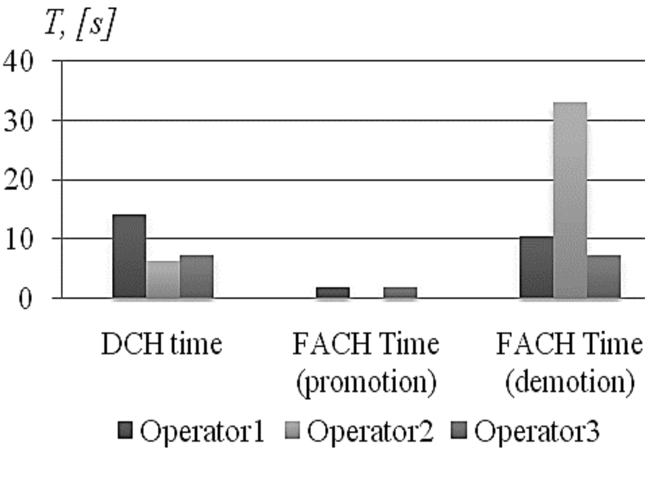

Fig. 8 – RRC states transition times

In terms of network resource utilization, Operator2 uses the longest DCH duration time, about two times longer than the other operators. That means that users have to compete between the total channel throughputs. During peaks, data download speed was varying quite significantly. Operator2 uses shortest DCH duration time, the download speed was quite constant.

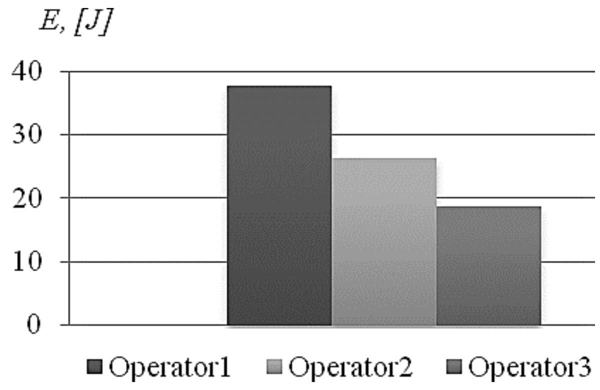

Fig. 9 – UE's consumed energy in different operators' UTRANs

Conclusion

In this paper we were researching the RRC machines of Lithuanian cellular operators' networks. The purpose of those experiments was to identify the network that could provide a best user internet browsing experience, the best user equipment battery consumption feature and the best radio network resource utilization scheme. We can state, that comparing all these partitions, Operator2 has the optimal configuration for user experience, UE device battery consumption and network resource utilization of RRC state machine point of view.

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Вплив налаштувань мобільних мереж на споживання енергіїелектронних блоків керування автомобілем

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Стаття присвячена дослідженню впливу налаштувань мобільної мережі на енергоспоживання електронних блоків керування автомобілів.Якість сигналу і покриття мобільних мереж також мають важливе значення як для користувачів так і для автомобільних приладів які використовують інформацію з мережі в режимі реального часу за допомогою хмарних технологій для передачі, обробки і зберігання даних.

Для вимірювання якості послуг Орган регулювання зв'язку використовує лише значення швидкості передачі (отримання) даних HTTP в мережах UMTS (3G) операторів (як зазначено у щорічному звіті CRA). Але швидкість - це далеко не все з тих вимог, які останнім часом висувають багато споживачів галузі. Крім того, вдосконалення тепер *також стосуються зменшення навантаження від сигналів, що виникають при встановленні, модифікації або роботі радіоканалу. Ще однією областю вдосконалення є накладні витрати на сигнали в ефірному інтерфейсі, коли передається мало даних, оскільки вони витрачають ресурси та спричиняють розряд акумулятора з точки зору мобільного телефону і інших приймаючих пристроїв, наприклад в автомобілі.*

Автори зупинились на мережі 3G UMTS (Універсальна система мобільного телекомунікаційного зв'язку), яка є однією з найпопулярніших технологій мобільного зв'язку 3G. Ми досліджуємо державний автомат RRC великих стільникових мереж, які працюють у Литві.

Зверніть увагу, що в мережі UMTS централізована основна мережа (CN) відповідає за забезпечення комутації та маршрутизації трафіку кінцевих користувачів. Усі функції управління мережею та необхідні бази даних також реалізовані в базовій мережі. Домен базової мережі далі поділяється на підкатегорії: обслуговуючий мережевий домен, домен домашньої мережі та домен транзитної мережі. Він складається з двох видів вузлів підтримки загальної пакетної радіостанції (GPRS) (GPN) - у 3GPP, названих шлюзом GSN (GGSN) та обслуговуючим GSN (SGSN). В свою чергу SGSN - центральний вузол домену з комутацією пакетів (PS). Він забезпечує функціональність маршрутизації та взаємодіє з базами даних (наприклад, Регістр домашнього розташування (HLR)) та управляє багатьма контролерами радіомереж (RNC).

Таким чином автори досліджували машини RRC мереж операторів стільникового зв'язку Литви. Метою цих експериментів було визначити, яка мережа може забезпечити найкращу якість роботи в Інтернеті, найкращу функцію споживання акумулятора обладнання та найкращу схему використання ресурсів радіомережі. Ми можемо стверджувати, що, порівнюючи всі ці вимоги, Operator2 має оптимальну конфігурацію для користувача, споживання батареї пристрою UE та використання мережевих ресурсів точки зору автомата RRC.

Ключові слова: автомобіль, мобільна мережа, електронний блок управління, система мобільного зв'язку, управління мережею.

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Влияние настроек мобильных сетей на потребление энергии электронных блоков управления автомобилем

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Статья посвящена исследованию влияния настроек мобильной сети на энергопотребление электронных блоков управления автомобилей.Качество сигнала и покрытие мобильных сетей также имеют важное значение как для пользователей так и для автомобильных приборов использующих информацию из сети в режиме реального времени с помощью облачных технологий для передачи, обработки и хранения данных.

Для измерения качества услуг Орган регулирования связи использует только значение скорости передачи (получения) данных HTTP в сетях UMTS (3G) операторов (как указано в ежегодном отчете CRA). Но скорость - это далеко не все из тех требований, которые в последнее время выдвигают многие потребители отрасли. Кроме того, совершенствование теперь также касаются уменьшения нагрузки от сигналов, возникающих при установлении, модификации или работе радиоканала. Еще одной областью совершенствования является накладные расходы на сигналы в эфирном интерфейсе, когда передается мало данных, поскольку они тратят ресурсы и вызывают разряд аккумулятора с точки зрения мобильного телефона и других принимающих устройств, например в автомобиле.

Авторы остановились на сети 3G UMTS (Универсальная система мобильной телекоммуникационной связи), которая является одной из самых популярных технологий мобильной связи 3G. Мы исследуем государственный автомат RRC крупных сотовых сетей, которые работают в Литве.

Обратите внимание, что в сети UMTS централизованная основная сеть (CN) отвечает за обеспечение коммутации и маршрутизации трафика конечных пользователей. Все функции управления сетью и необходимые базы данных также реализованы в базовой сети. Домен базовой сети дальше делится на подкатегории: обслуживающий сетевой домен, домен домашней сети и домен транзитной сети. Он состоит из двух видов узлов поддержки общей пакетной радиостанции (GPRS) (GPN) - в 3GPP, названных шлюзом GSN (GGSN) и обслуживающим GSN (SGSN). В свою очередь SGSN - центральный узел домена с коммутацией пакетов (PS). Он обеспечивает функциональность маршрутизации и взаимодействует с базами данных (например, Регистр домашнего местоположения (HLR)) и управляет многими контроллерами радиосетей (RNC).

Таким образом авторы исследовали машины RRC сетей операторов сотовой связи Литвы. Целью этих экспериментов было определить, какая сеть может обеспечить наилучшее качество работы в Интернете, лучшую функцию потребления аккумулятора оборудования и лучшую схему использования ресурсов радиосети. Мы можем утверждать, что, сравнивая все эти требования, Operator 2 имеет оптимальную конфигурацию для пользователя, потребление батареи устройства UE и использования сетевых ресурсов точки зрения автомата RRC.

Ключевые слова: автомобиль, мобильная сеть, электронный блок управления, система мобильной связи, управления сетью.

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