Delay-Sensitive Applications in VANET and Seamless Connectivity: The Limitation of UMTS Network

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Summary
Multi-interface handheld devices enabling radio link connections to varieties of wireless networks (i.e 3G cellular, Wi-Fi, WiMAX) can provide seamless connectivity. With seamless connectivity, VANET safety applications are emerged. Currently, seamless connectivity has been promoted in 3G cellular environments offering a large coverage area and high bandwidth. Even though, 3G cellular networks offer high bandwidth, they may not support end-to-end delay guarantee which is the most important property of VANET safety applications. Thus, the purpose of this article is to investigate whether UMTS cellular networks can support seamless connectivity for delay sensitive applications in VANET. From the study, seamless connectivity for delay-sensitive applications is feasibly achieved in UMTS cellular network if a mobile is in CELL_DCH and CELL_FACH states. CELL_PCH and URA_PCH states might support most of applications except action games and safety applications. However, the UMTS network is not suitable for life-critical applications due to the short-lived duration of the CELL_DCH and CELL_FACH states. The inactivity timers of the CELL_DCH and CELL_FACH states possibly expired when the safety message transmission is needed.
Key words:
seamless connectivity, delay-sensitive application, RRC states,VANET.

1. Introduction

Smart devices are now equipped with multiple wireless interfaces such as 3G cellular network, WiFi or WiMAX, etc. These technologies differ in properties such as delay, communication range, bandwidth, billing cost but users basically need to be always connected in a way that best suits their applications and preferences. Thus the concept of Always Best Connected (ABC) is emerged. The definition of the word “best” depends on several aspects such as personal preferences, application requirements, available network resources, security, corporate policies and network coverage areas, etc [1]. The ABC thus promises the seamless connectivity which provides the smooth connections and quality of service (QoS) requirements of the applications.

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To achieve the seamless connectivity in heterogeneous networks, the network selection is required. Several network selection approaches based on Multi-Criteria Decision Making (MCDM) techniques [2-7], fuzzy control theory [8-10], fuzzy logic and genetic algorithms [11],[12], fuzzy logic and MCDM techniques [13], artificial neural network [14], decision tree learning [15],[16], game theory [17],[18], are proposed. They generally gather QoS parameters from applications and network metrics of available wireless networks from data link layer. These parameters are then processed and evaluated by the proposed techniques to select the optimum network regarding the criteria.
The 3G technology currently claims to provide the seamless connection by their large coverage area and high data rate offer, however, high data rate might not guarantee end-to-end latency which is crucial for delay-sensitive applications. Whether the cellular network can support the seamless connectivity for delay-sensitive applications is skeptical. Thus, this paper studies whether 3G cellular networks can offer the seamless connectivity for delay-sensitive applications in vehicular networks. The contents are organized as follows. In section 2, the foundations including characteristics and architectures of vehicular networks, requirements of delay-sensitive applications, and Universal Mobile Telecommunications System (UMTS) cellular network are reviewed. Whether UMTS cellular network is capable of supporting seamless connectivity for delay-sensitive applications on vehicular networks are investigated in section 3. Finally, in section 4, the conclusion is explained.

2. Foundations

2.1 Architectures, Characteristics and Applications of Vehicular Networks

Vehicular Network, also known as Vehicular Ad-hoc Network (VANET), is an emerging wireless network envisioned for supporting Intelligent Transport System

(ITS) applications. There are three main types of applications based on the objectives [23].

i) *Active road safety applications* are to reduce the number and severity of traffic accidents by broadcasting safety-related information to drivers. The examples of active safety applications are collision warning, and overtaking vehicle warning, etc.

ii) *Traffic efficiency and management applications* provide the improvement of traffic flow, traffic coordination and traffic assistance which benefits the efficient consumption of time and fuel.

iii) Infotainment applications are similar to the traditional applications such as media download, emails, games, and video conferences, etc.

VANET is formed by moving vehicles equipped with wireless interfaces [22]. In VANET, there are two main types of communications architectures: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). V2V allows vehicles directly communicate to others without infrastructure for local area communications. The wireless technologies deployed for V2V architecture might be Dedicates Short Range Communications (DSRC), WiFi, Bluetooth, Zigbee. On the contrary, in V2I, vehicles communicate to others via wireless module equipped on the infrastructure such as traffic lights or mobile base stations. The wireless technologies in V2I architecture could be Infrared, cellular network, WiFi, DSRC, Satellite and WiMAX. Fig. 1 shows an example of V2V and V2I architectures.

VANET is considered as a special type of mobile networks with unique behaviors and characteristics as follows [22].

i) Mobile devices have no power constraints because a vehicle can provide continuous power to the devices

ii) The pattern movements of vehicles are more likely predictable, i.e., along a road. The future positions can be estimated from the current position and speed from Global Positioning System (GPS) and a roadmap.

iii) The environments are highly dynamic due to the high movement of vehicles. The specific wireless access technologies might not be always available and supports the QoS requirements of the applications throughout the journey.

2.2 QoS requirements of delay-sensitive applications

Different VANET applications require different QoS. For those applications that need end-to-end latency less than specified values are called delay-sensitive applications. For example, broadcast messages of safety applications must be delivered to the neighborhoods within 100 ms [23],[24]. One-way latency of interactive game is bounded around 80-250 ms depending on game genre [25],[26]. The video conference and VoIP require end-to-end latency less than 150 ms for good quality but not more

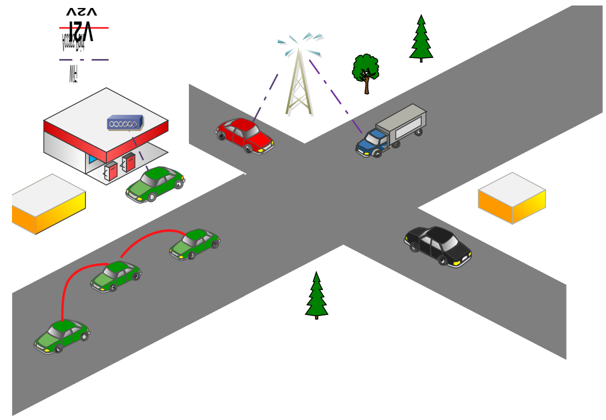

Fig. 1 An example of V2V and V2I architecture

than 400 ms for acceptable quality [27]. Table 1 summarizes one-way end-to-end latency requirements and traffic characteristics of delay-sensitive applications including video conference, VoIP, gaming and safety applications is shown in Table 1.

2.3 Universal Mobile Telecommunications System (UMTS) Cellular Network

Universal Mobile Telecommunications System (UMTS) is the third generation (3G) of cellular network. The architecture of UMTS packet switching network consists of three main parts; i) User Equipment (UE), ii) UMTS Terrestrial Radio Access Network (UTRAN) and iii) Core Network (CN), as shown in Fig. 2 [28]. The UE is the mobile station. The UTRAN is a group of base stations, called Node Bs, and Radio Network Controllers (RNCs). The Node B controls several cells and physical layer processing, e.g. channel coding, rate adaptation, etc. The RNC performs controlling functionality such as load and congestion control, radio resource management and handover detection, etc.

Table 1: The summary of one-way end-to-end latency requirements and the traffic characteristics of delay-sensitive applications

Delay-Sensitive Applications	Latency Requirements (ms)	Characteristics of Traffic
Video Conference	preferred: < 150 acceptable: 150-400	continuous traffic
VoIP	preferred: < 150 acceptable: 150-400	continuous traffic
Game	action: <80 interactive: <250	continuous traffic
Safety applications	Life-critical safety <100 Safety warning <100	event-driven periodic

The CN consists of Serving GPRS Support Nodes (SGSNs) and Gateway GPRS Support Nodes (GGSNs). An SGSN is responsible for routing data to the relevant GGSN to external network, mobility management of mobile user from one SGSN to another, and protocol conversion. A GGSN is a gateway to external networks. It routes packets coming from external network to the relevant SGSN and vice versa. The GGSN also allocates dynamic IP addresses to mobile either by itself or with the help of a DHCP or RADIUS server.

The first data service technology in the UMTS network, Wideband Code Division Multiple Access (WCDMA), provides maximum bit rate of 144 kbps, 384 kbps, and 2 Mbps under high mobility, in urban environments, and in static environments, respectively. The data is modulated by QPSK modulation scheme. The improved protocol of WCDMA is High Speed Packet Access (HSPA), known as 3.5G. The software and hardware upgrades are implemented on UTRAN. The HSPA is based on QPSK and 16-QAM modulation scheme. It offers peak data rate of 7.2 Mbps in the downlink and 1.44 Mbps in the uplink [29] and reduces latency as well.

3. The study on seamless connectivity for delay sensitive applications by UMTS cellular network on VANET

The prime concern of seamless connectivity for delay-sensitive applications on VANET is the total end-to-end latency of packet transmission. The total end-to-end latency refers to the interval between the request of packet transfer and the arrival of the packet on the server. The supporting network must guarantee the total end-to-end latency throughout the session. Besides, the service area of supporting networks should be considered since nodes in VANET basically travel in large area. The UMTS cellular network tends to support the seamless connectivity for the delay-sensitive applications due to its benefit properties;

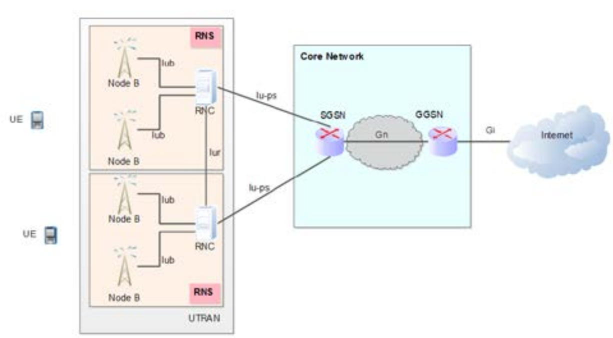

Fig. 2 The architecture of UMTS network (WCDMA/HSPA)

large geographical service area, high bandwidth offer and numerous subscribers.

In this work, the UMTS cellular network is investigated whether it can support seamless connectivity for the delay-sensitive applications possibly emerged on VANET. Only Mobile-Originated (MO) packet-switched data service, where the mobile initiates the packet transfer, is interested. The primary investigation of the total end-to-end latency is based on the low mobility scenario without any handover as illustrated in Fig. 3.

To access packet-switched data service, the mobile must be allocated the radio resource, GPRS-attached and Packet Data Protocol (PDP) context activated. These overhead processes, called the packet session setup, contribute the significant delay. Additionally, the UMTS cellular networks employ the Radio Resource Control (RRC) states, unique resource control mechanisms, to efficiently utilize the scarce radio resource of the networks and the limited energy of the mobiles. The transitions of the RRC states are triggered by the inactivity duration of data transfer and the amount of data traffic. These transitions also incur the total end-to-end latency even though the mobile is already GPRS-attached and PDP context activated.

Thus, the study of the total end-to-end delay on UMTS cellular network is divided into two cases: i) the mobile is initially in idle mode, not GPRS-attached and not PDP context activated, and ii) the mobile is already in connected mode, GPRS-attached, and PDP context activated (always-on connectivity).

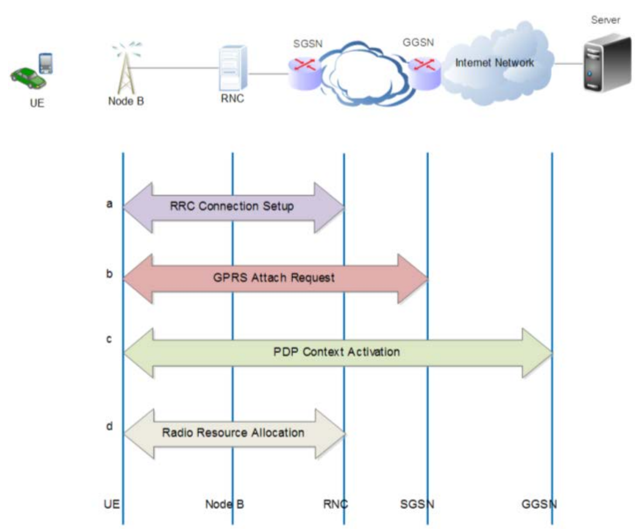

Fig. 3 The network for end-to-end latency evaluation on the UMTS network and the overall procedures of packet session setup

3.1 The mobile is initially in idle mode

The default mode of the mobile after being switched on is idle mode. The mobile in idle mode does not have a Radio Resource Control (RRC) connection. Thus, it cannot transfer any data. The RRC performs radio-related functions, such as radio link establishment and maintenance between the mobile and the UTRAN [30]. If the mobile has packets to be transmitted, the packet session setup must be carried out as shown in Fig. 3. The overall procedures of packet session setup are divided into four phases [31] as follows:

phase (a) *Radio Resource Control (RRC) connection setup:* The mobile in idle state establishes RRC with the RNC. The purpose of the RRC connection setup is to change the state from idle mode to connected mode [32].

phase (b) *GPRS attach request:* After the RRC connection setup is established, GPRS attach request is sent from UE to the SGSN via RNC. The authentication and ciphering request is processed in this session. After GPRS attach accept sent to the UE, the UE is GPRS-attached. This procedure makes the presence of the mobile known to the SGSN in packet switch core network. All this session involves GPRS mobility management.

phase (c) *Packet Data Protocol (PDP) context activation:* After the GPRS attachment is completed, the mobile still cannot send any packets since it still has no IP address. PDP context activation procedure is used to create the tunnel of data path from the mobile to the GGSN via SGSN. An IP address, also called a PDP address, is assigned in this session. The data associated with the PDP context contains information about the type of packet-switching network, PDP address, the reference of GGSN, and the requested QoS.

phase (d) *Radio resource allocation:* Radio resource allocation is a procedure that the radio bearer is reconfigured for resource allocation between RNC and UE. The involved messages are the radio link setup between the RNC and the Node B and the setting up of the radio bearers between the RNC and the UE. After the setting is completed, the radio resource is allocated. The UE is capable of supporting the packet-switched data session. Hereafter, the UE is ready to transfer data.

Typically, the latency for a mobile to transit to a state where it can send or receive data is called control-plane latency [32]. The c-plane latency of the packet session setup from phase (a) to (d) is denoted by $t_{c\text{-}plane,setup}$. The end-to-end latency, t_{e2e}, is defined as the delay that the packet experiences from the mobile to the server according to Fig. 3a. Thus, if the mobile in the idle mode requests to transfer data, the total one-way end-to-end latency, $t_{total,idle}$, is the summation of the c-plane latency of packet session setup and the end-to-end latency expressed in Eq. 1.

$$t_{total,idle} = t_{c\text{-}plane,setup} + t_{e2e} \tag{1}$$

From the literature survey, in static environments, the c-plane latency of the packet setup, $t_{c\text{-}plane,setup}$ on WCDMA is around 3500-5200 ms [31], [33], [34] while on HSPA is around 550-3500 ms [31],[32],[35],[36],[37]. This c-plane latency is much higher than the one-way latency requirements of the delay-sensitive applications in Table 1. It is obvious that the UMTS cellular network, both WCDMA and HSPA technologies, cannot support the seamless connection for delay-sensitive applications if the data transfer is requested when mobile is in the idle mode. The example of the scenario is that the user switches data transfer from the former type of network (WiFi) to the UMTS network in the middle of application session. The $t_{c\text{-}plane,setup}$ will cause the unsmoothed data transfer during network switching.

3.2 The mobile is already in connected mode, GPRS attached, and PDP-context activated

After the mobile is turned on, it remains in idle mode. Once the RRC is established, the mobile turns into connected-mode. The main operational modes of the mobile are idle mode and connected mode as shown in Fig. 4 [38]. The connected mode is further divided into four states: dedicate channel (CELL_DCH), forward access channel (CELL_FACH), paging channel (CELL_PCH) and UTRAN registration paging channel (URA_PCH) states. The objectives of the RRC states are to minimize the power consumption of the mobile and to effectively utilize scarce radio spectrum. All the states are described as follows:

CELL_DCH: After the confirmation of the RRC connection setup, the UE enters the CELL_DCH or the CELL_FACH state [39]. In the CELL_DCH state, the UE is known in the accuracy level of a cell. The CELL_DCH state is the highest state in which the mobile consumes the most energy but offer the maximal data transfer and minimum transfer. In this state, the dedicated physical channels are allocated to the mobile in the uplink and the downlink.

CELL_FACH: The mobile in this state is also known in the accuracy level of a cell. The CELL_FACH state is lower than the CELL_DCH state. The mobile in the CELL_FACH state is assigned a default common or shared transport channel. The energy consumption in the CELL_FACH state is around 50% of the energy consumption in the CELL_DCH state. The mobile transmits user data through the random access channel (RACH) in the uplink. The data rate is typically less than 16 kbps [40]. The maximum data transfer via FACH in the downlink is 32 kbps [40]. This state is used when data traffic is low.

CELL_PCH and URA_PCH: The location of the mobile in the CELL_PCH state is known in the accuracy level of a cell. The mobile in the URA_PCH state is known in the

URA level, a superset of multiple cells. The mobile in these states consumes energy around 1-2% of CELL_DCH state. The mobile in these states cannot transfer any data and is only reachable via paging message. However, if the PDP context is still retained, the mobile will be promoted to the CELL_FACH state. A data transfer session could be reconnected. In the case of cell reselection, the mobile in the CELL_PCH state is promoted to the CELL_FACH state and initiates a cell update procedure in the new cell. Afterwards, it falls back into the CELL_PCH state if neither the mobile nor the network has any more data to be transmitted [39]. Similarly, the mobile in the URA_PCH state moves to the CELL_FACH state and initiates the URA update towards the network and falls back into the URA_PCH state.

Although the mobile is already connected for packet-switched data services, its RRC states are interchangeable. The transitions of each RRC states are triggered by the amount of transferred data, cell update, or the inactivity timer as shown in Fig. 4. For example, the mobile in the CELL_DCH state will be demoted to the CELL_FACH state if the inactive period of data transfer is greater than the inactivity timer of the CELL_DCH state. The inactivity timers of the RRC states are controlled by network operators. The mobile in the CELL_PCH or URA_PCH state will be promoted to the CELL_FACH and then to the CELL_DCH state if it has data to be transferred.

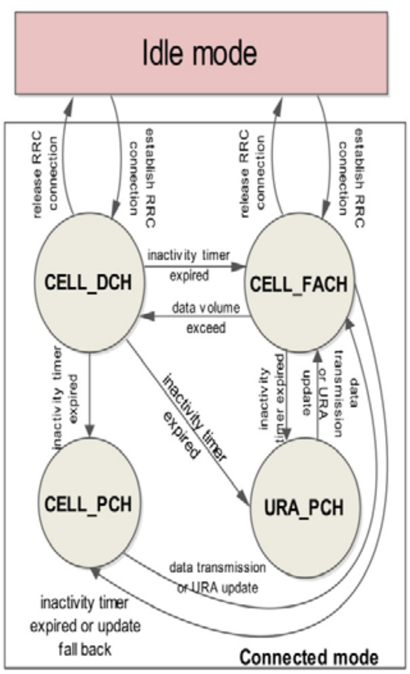

Fig. 4 The RRC state overview

When the mobile changes states from the lower to higher state, this introduces additional delay. The duration of the state transition from the lower state to the higher state is called the promotion delay, denoted by $t_{promote}$. From the literature survey [31], [33-37], [41-43], the inactivity timers and the promotion delay highly vary and depend on technologies (WCDMA or HSPA) of UMTS networks. The range of the inactivity timers in the RRC states from several papers [31,33-37,41-43], is concluded in Table 2. T_1, T_{2a}, T_{2b}, and T_3 in Table 2 denote the inactivity timer of the state transition from CELL_DCH state to CELL_FACH state, CELL_FACH state to CELL_PCH state, CELL_FACH state to idle state, and CELL_PCH state to idle state, respectively. The range of the promotion delay ($t_{promote}$) from [31-33,35-36] is also summarized in Table 3.

Only the mobile in the CELL_DCH and CELL_FACH state can immediately send data. However, if the mobile in the CELL_PCH or URA_PCH state wants to transmit the data, it must change to CELL_FACH state. This state transition produces the additional delay to the total end-to-end latency. Thus, if the data transfer is required when the mobile is already in connected mode, GPRS-attached and PDP context activated, the total end-to-end latency, $t_{total,connected}$, is the summation of the promotion delay ($t_{promote}$) and the end-to-end latency (t_{e2e}) as Eq. 2.

$$t_{total,connected} = t_{promote} + t_{e2e} \tag{2}$$

Note: $t_{promote}$ occurs whenever mobile changes states from the lower to higher states.

Table 2: The range of inactivity timers of RRC states

Inactivity timer	The range of inactivity timer
T_1 (CELL_DCH → CELL_FACH)	500 -10,000 ms
T_{2a} (CELL_FACH → CELL_PCH)	2000-45,000 ms
T_{2b} (CELL_FACH → Idle)	4000-75,000 ms
T_3 (CELL_PCH → Idle)	30 minutes

Table 3: The range of promotion delays of RRC states

State transition	The range of promotion delay ($t_{promote}$)
CELL_FACH → CELL_DCH	500 – 1500 ms
CELL_PCH → CELL_FACH or URA_PCH → CELL_FACH	14-100 ms

Table 4: The latency requirements and feasible RRC state supporting seamless connectivity

Delay-sensitive applications	Latency Requirements (ms)	Characteristics of Traffic	RRC state when data transfer is required			
			DCH	FACH	PCH	idle
Video Conference	preferred: < 150 acceptable: 150-400	continuous traffic	✓	✓	✓	x
VoIP	preferred: < 150 acceptable: 150-400	continuous traffic	✓	✓	✓	x
Game	action: <80 interactive: <250	continuous traffic	✓ ✓	✓ ✓	x ✓	x x
Safety applications	Life-critical safety <100 Safety warning <100	event-driven periodic	✓ ✓	✓ ✓	x x	x x

From the Eq. 2, the UMTS cellular networks possibly support the seamless connectivity of the delay-sensitive applications if the $t_{total,connected}$ is less than the latency requirements of the delay sensitive applications in Table 1. Whether the state in which the mobile possibly support the seamless connectivity is roughly estimated by the maximal value of $t_{promote}$. If the $t_{promote}$ of the state of interest in Table 3 is less than the latency requirement of the investigated application, the mobile in that state possibly supports the seamless connectivity. Thus, there are three conditions that possibly support the seamless connectivity; i) the mobile in the CELL_DCH state, ii) the mobile in the CELL_FACH state and iii) the mobile in the CELL_PCH state.

The mobile in the CELL_DCH has no promotion delay and can immediately transfer the data. Hence, the mobile in the CELL_DCH possibly supports the seamless connectivity for the delay-sensitive applications as long as t_{e2e} is less than the latency requirements.

In the CELL_FACH state, the mobile also immediately transfers data. Although the uplink data rate in the CELL_FACH state is around 16 kbps, the mobile is feasible to support all applications since the sizes of packets are generally small. If the amount of data is larger than the buffer threshold, the mobile will be promoted to the CELL_DCH state.

When the mobile in the CELL_PCH state wants to transmit data, it must move to CELL_FACH state and then to CELL_DCH state. The maximal promotion delay is around 100 ms. Thus, the mobile in CELL_PCH or URA_PCH state probably supports video conference, VoIP and interactive game applications. This assumption is true if and only if t_{e2e} in Eq. 2 is fulfilled. The latency requirements of delay-sensitive applications and the feasible RRC states supporting seamless connectivity are summarized in Table 4.

One factor that must be considered is the longest duration of intermediate packets sent from the mobile in order to maintain the feasible RRC states which support the seamless connectivity in Table 4. This duration is called idle period. Refer to the inactivity timer of the RRC states in Table 2, the maximal idle period is calculated by the summation of inactivity timers before that mobile is demoted to the state infeasible to support seamless connectivity. For example, if the last state of mobile transmitting safety message is in the CELL_DCH state, the maximum idle period is the summation of interactive timer before a mobile turns into the CELL_PCH state which cannot provide seamless connectivity. The longest idle period is the sum of the inactivity timer of CELL_DCH state (T_1) and the inactivity timer of CELL_FACH state (T_{2a} or T_{2b}). The maximum idle periods to maintain feasible RCC states for delay-sensitive applications are summarized in Table 5.

From the fact that life-critical safety messages are event-triggered and rarely transmitted, this will cause inactivity timer expires. The mobile in the CELL_DCH or CELL_FACH state will be demoted to the CELL_PCH/URA_PCH or even idle state. In order to maintain in the CELL_DCH or CELL_FACH state, the mobile must periodically send probe packet. The probe packets waste the channel bandwidth and inappropriately utilize the scarce resource in cellular system. Thus HSPA and WCDMA technologies in UMTS network might be not suitable network for safety applications.

VoIP, video conference and gaming are feasibly supported by cellular systems since the traffic of these applications is continuous. The data packets are transmitted until the session is ended. The idle duration barely occurs except the users terminate programs.

4. Conclusion

Seamless connectivity attracts both academic and commercial world. Commercial companies offered applications in order to keep a mobile always being best connected anywhere. For delay-sensitive applications, the seamless connectivity means that the latency requirements of applications must be guaranteed by a network. The total end-to-end latency which the packet experiences must not exceed the requirement of the application. From the study,

Table 5: The summary of maximum idle periods to maintain feasible RCC states for delay-sensitive applications

Delay-sensitive applications	Maximum idle period that can still support seamless connectivity when the last state is		
	CELL_DCH	CELL_FACH	CELL_PCH/URA_PCH
Video Conference	$T_1 + T_{2a} + T_3$, $T_1 + T_{2b}$	$T_{2a} + T_3$, T_{2b}	T_3
VoIP	$T_1 + T_{2a} + T_3$, $T_1 + T_{2b}$	$T_{2a} + T_3$, T_{2b}	T_3
Game:			
action	$T_1 + T_{2a}$, $T_1 + T_{2b}$	T_{2a}, T_{2b}	-
interactive	$T_1 + T_{2a} + T_3$, $T_1 + T_{2b}$	$T_{2a} + T_3$, T_{2b}	T_3
Safety applications:			
Life-critical safety	$T_1 + T_{2a}$, $T_1 + T_{2b}$	T_{2a}, T_{2b}	-
Safety warning	$T_1 + T_{2a}$, $T_1 + T_{2b}$	T_{2a}, T_{2b}	-

seamless connectivity for delay-sensitive applications can be achieved by UMTS cellular network if and only if a mobile is already in RRC connected mode. The mobiles in the CELL_DCH and CELL_FACH state tend to support most of delay-sensitive applications such as video conference, VoIP, and game, except safety applications. This is because the safety applications rely on an event-driven approach. There is a high possibility that when the safety message transmission is required, the inactivity timers of the CELL_DCH and CELL_FACH state have already expired. This is due to the event-driven characteristic of the safety applications. Although probe packets can keep mobile being in the CELL_DCH and CELL_FACH state, they waste the bandwidth and limited radio resource. Hence, it can be deduced that UMTS cellular network is not suitable for seamless connectivity for life-critical safety applications.

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