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Congestion Recognition in Mobile Networks

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Abstract

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Smartphones have proven to be popular among people around the world, due to a long list of features and capabilities. Such great benefit will multiply once internet connectivity is available. Mobile phones operating systems are evolving quickly to meet end user expectations, furthermore, operating systems typically include a market or store where millions of mobile applications are available and can be easily installed. The growth of the number of applications, smartphone users and the number of applications installed by a single user is increasing the load on the mobile network, given that most of the applications require internet connectivity to function. The increased load can evolve into congestion that can be felt by users, for example, it will take longer time to load a web page.

The goal of this study was to come up with an algorithm that is able to detect congestion in mobile network as it happens. The implementation of the algorithm runs autonomously in a smartphone, where it analyses the traffic, takes samples, and collects data about network towers location. In order to validate and test the algorithm, Android implementation of the algorithm was developed in addition to a supporting web server. The web server was used to provide storage and real-time view on algorithm calculations. The Android implementation got executed over all three Finnish mobile network operators, and a mobile network simulator box.

The algorithm has proven to be novel and has led to a granted patent in the US. Furthermore, the study concluded that real-time congestion detection can be extremely beneficial for mobile operators where they can get insights from the user prospective, in addition to the countless cases where application developers can alter their application connectivity logic according to congestion situations.

Additional research could be conducted using the algorithm and the implementation described in this study. For example, to build an application to compare radio access performance between operators in different areas, so end users can pick the operator with the best quality of service in their areas.

Keywords	LTE, Congestion, Networks, Mobile, HSPA, UMTS, Android, RRC, RAN

Contents

Definition of terms and abbreviations

VoIP	*Voice over Internet Protocol*
GSM	*Global System* for *Mobile* Communications, also known as 2G
UMTS	*Universal Mobile Telecommunications System*, also known as 3G
LTE	*Long Term Evolution*, also known as 4G
EPS	*Evolved Packet System*
UTRAN	*Universal Terrestrial Radio Access Network*
E-UTRAN	*Evolved Universal Terrestrial Radio Access Network*
HSPA	*High Speed Packet Access*
SIB	*System Information Blocks*
WCDMA	*Wideband Code Division Multiple Access*
IP	*Internet Protocol*
UDP	*User Datagram Protocol*
TCP	*Transmission Control Protocol*
HTTP	*Hypertext Transfer Protocol*
DRX	*Discontinuous Reception*
RRC	*Radio Resource Control*
RACH	*Random Access Channel*
FACH	*Forward Access Channel*
PCH	*Paging Channel*
DCH	*Dedicated Channel*
UE	*User Equipment,* in the scope of this study, it refers to a mobile phone.
CN	*Core Network*
SOC	*System On Chip*
CRA	*Congestion Recognition Algorithm*
CAC	*Connection Admission Control*
NAT	*Network address translation*
PCC	*Potential Congestion Case*
CCC	*Confirmed Congestion Case*
PCD	*Positive Congestion Decision*
Sample	Radio packet access 'setup time'
RSCP	*Received Signal Code Power*
SNR	*Signal-to-Noise Ratio*
IMEI	*International Mobile Equipment Identity*

1 Introduction

A mobile network infrastructure works under the assumption that the devices enjoying packet access offered by an operator would not be in connected mode all at once. That assumption is what allows the network to serve a larger number of mobile devices. In the hands of a typical user, a mobile device will alternate between connected mode and idle mode as he/she surfs the internet and downloads content. What is expected from the device after the usage session is over is to be in idle mode which will allow the operator network to release some resources which have been used by that user and allocate it to another user.

The problem arises when the device is still alternating between connected and idle mode even without any user interaction. That is a result of the applications being installed on the mobile device trying to access the internet to communicate with their content provider to check for updates or to keep the TCP connection alive in order to push updates or VoIP calls immediately to the user.

Now this represents a challenge to the operator as more and more smart phones are joining the network and each one of them is loaded with access demanding applications. This naturally leads to less capacity and a huge signalling load over the network, which requires expensive hardware updates and investments in new technologies. That can be easily seen by operators running after 4G LTE-advance network as it provides bigger packet access capacity. However, that will only buy them some time, as the number of easy and free to install applications is increasing exponentially.

There are many ways to optimize mobile traffic and prevent overloading the network. However, there are times that the network is under heavy load. The ultimate goal of this study is to create an algorithm capable of recognizing congested overloaded networks. In order to achieve such a goal, a piece of software running on Android mobile operating system was developed, in addition to a web application which monitors and stores algorithm output in real-time.

Congestion can happen on the radio part or in the core part of the network. This study focuses on detecting the congestion in the radio part of the network and can even detect it on cell level. This early detection can take place before reaching the critical congestion level where packet call establishments get rejected.

The congestion detection algorithm lives in the mobile device and takes 'samples' and other measurements as inputs. There are also parameters that can be changed to tweak its detection sensitivity.

The study starts by explaining mobile network basics then moving gradually towards describing the background of the problem. In addition to presenting some technical aspects that are essential for understanding what could cause congestion in mobile networks.

In the third section the targeted features of the congestion recognition algorithm are set. In addition, there can be found a detailed description of the algorithm mechanics and components, which are also available in the patent application. Thereafter, the implementation journey challenges and solutions are presented with enough details that enable the reader to replicate the experiment.

The fourth section contains the results of this study. The implementation is put under a controlled congestion environment using a network simulator machine, where it was able to autonomously detect congestion. The implementation also reviled some differences in packet call establishment time between three Finnish operators.

In the last section of this study, it is recommended to include such a congestion detection mechanism as part of modern mobile operating systems. The benefits will be shared between mobile operators, application developers and eventually the end users.

2 Background

This section presents current knowledge around the topic and how nowadays practices are leading to the problem addressed in this research. The following subsections also provide the necessary understanding on today's technologies in the fields of networking and mobile data packet access.

2.1 Mobile Device as Voice and Data Transceiver

Initially, the idea behind inventing a mobile device was to provide the user with the ability to make phone calls wirelessly and to accept phone calls from other network subscribers. Operators carried on the task of establishing the connection and maintaining the network health and resources. Operators charged their subscribers for these services. The more services offered to subscribers, the more profit they would gain. On the other hand, mobile device manufactures are trying to sell more devices shipped with smart and advanced operating systems that rely heavily on data exchange with the internet.

2.2 Circuit-switching (CS) and Packet-switching (PS)

Circuit-switching creates a dedicated channel between at least two subscribers in order to guarantee the required bandwidth to complete a voice call or exchange a shot-message. However, it quickly became clear that circuit-switching is not the optimal way to transmit and handle internet packets. As a result, packet-switching became the clear path to go forward.

Multiple technologies have emerged to satisfy the need for packet access, most notably GPRS found in the so-called 2G and UMTS/HSPA found in 3G. Figure 1 illustrates the technologies and packet domains.

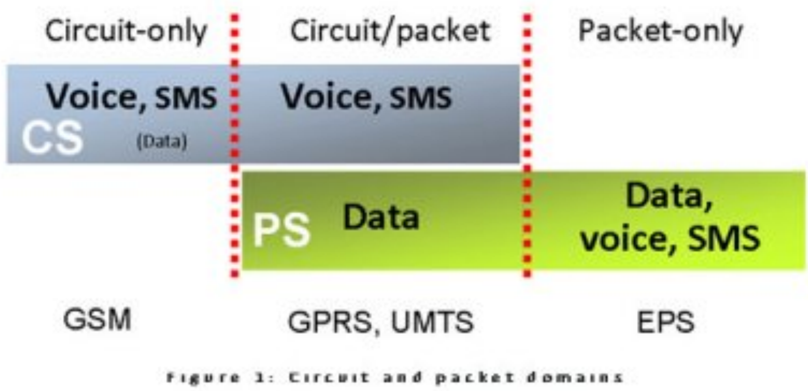


Figure 1. Circuit and packet domains [1].

It is noticeable that in 4G or EPS (Evolved Packet Service) even voice service will be moved from circuit switching to packet switching, which will increase the load for packet access. The more load the more importance given to congestion detection methods.

2.3 IP Based Networks End-to-end

During the LTE development of new specifications, the goal was to move from UTRAN to E-UTRAN. It was logical to choose IP packets as mean of transferring information between mobile devices and RAN, as the Core Network is already IP based. The Core Network (CN) would simply act as an Internet gateway for connected mobile devices. The different mobile network architectures, on a general level, are shown in Figure 2.

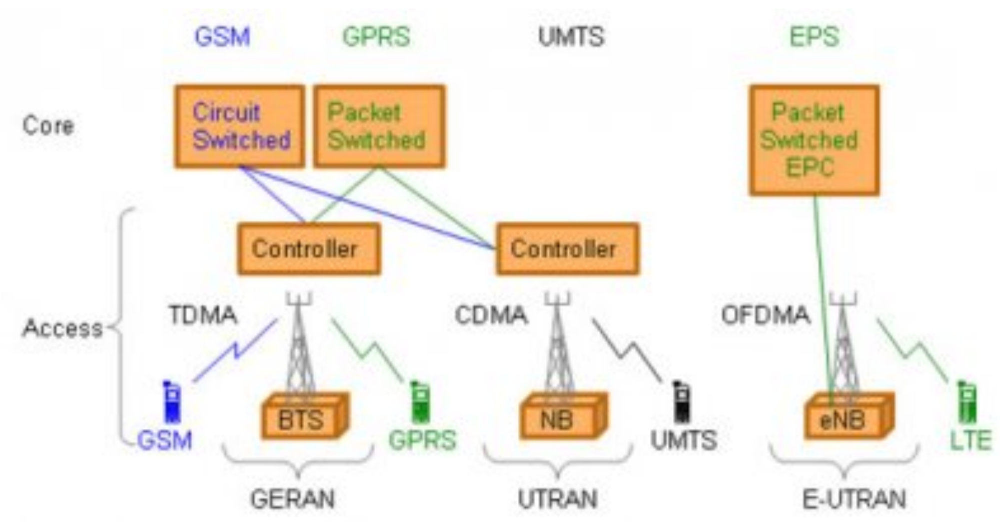


Figure 2. Radio Access Network from GSM to LTE [2].

In 3G's UTRAN some of the services related to packet access were still relying on circuit switching, however, in 4G's E-UTRAN it is all IP based even for signalling and control messages.

2.4 Packet Encapsulation

The main characteristics of a typical IP packet are its source address, destination host and payload. The payload is usually occupied by a transport protocol where its header would contain more details such as source and destination ports. Transport protocol payload can be application specific data or some other protocol, for example, HTTP.
This flexible and multi-layered structure of IP is the reason why telecommunication industry is heavily based on it.

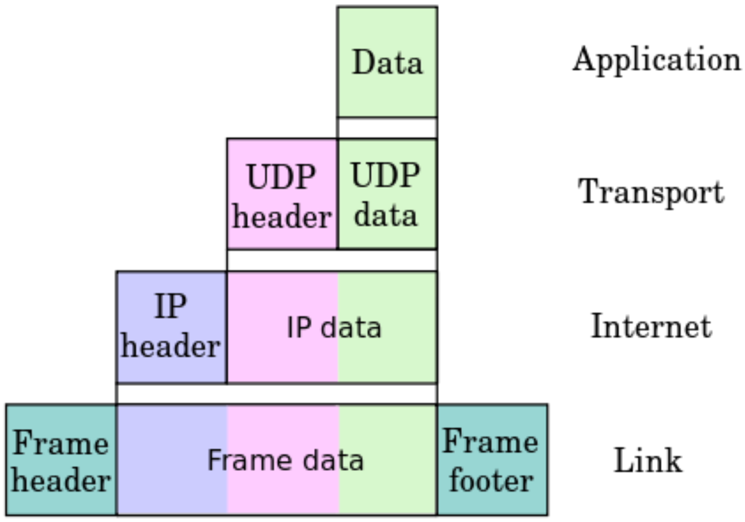


Figure 3. Packet encapsulation example for UDP [3].

In most cases application developers are dealing with the 'Data' in 'Application' layer as seen in Figure 3. The 'Transport', 'Internet' and 'Link' layers are being taken care of by the operating system. This packet's 'Data' shown in Figure 3 could be carrying a segment of bytes as part of a VoIP call.

2.5 Modern Mobile Operating Systems

There has been a noticeable development in mobile operating system features. Concurrency and background multithreading are available in any modern OS, in addition to powerful computing abilities that can under-clock its frequency to reduce power consumption. These set of feature have enabled mobile applications to be in always-on mode, and easily communicating to their content providers in the background using packet access. While such features are pretty useful and attractive to the end user, modern operating systems have caused extra load over the radio network. The reason is, obviously, mobile application developers who are always aiming at customer satisfaction and they will happily utilize all the communication resources available to reach their goal.

Operating systems have also provided developers with facility to wake up the device periodically from deep sleep, which will turn CPU on, in order to complete some tasks. Usually such tasks include sending a packet to keep the connection alive to its content server through Internet infrastructure. Otherwise, the connection's socket information will get a lower priority in networking routers memory and finally it is dropped.

2.6 Mobile Applications Explosion

All major mobile operating systems have introduced easy ways for users to download applications, which resulted into billions of mobile application downloads *'More than 60 billion total apps have been downloaded…That puts Apple about on par with the Android'* [4]. There is nothing stopping the user from downloading more and more applications, especially, when mobile hardware specifications are getting better and there are huge numbers of free of charge applications to try out. *'Nielsen estimates that in 2012 the average number of apps in a mobile device was 41, compared to 32 in 2011.'* [5]P.8.

It is quite appealing to discover new applications; however, in many cases a user would not really bother to remove the applications, which are no longer in use. This has implications, which will be explained further in this study.

2.7 Data Plane and Control Plane

Date plane is the channel where all user specific data goes. In order to have sustainable data flow between a mobile device and Internet servers, there is another data being exchanged to achieve that, which is going over control plane as shown in Figure 4. Let's say a user is downloading a video from some server on the internet, it will be going over the data plane and the user might be charged for those bytes being transferred, however, there is another kind of data going over the control plane to insure that data plane is functioning properly.

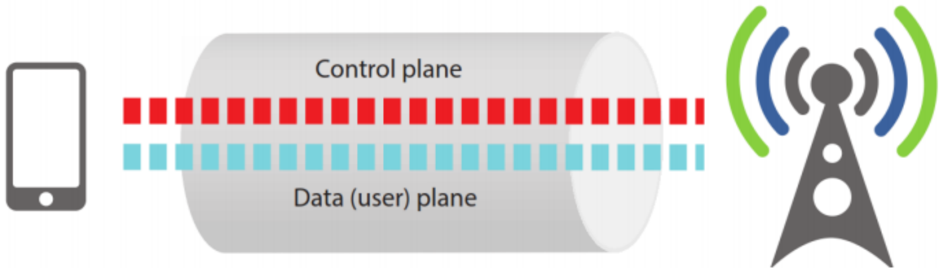


Figure 4. Control plane is essential part for data flow [5]

In matter of fact, it is not possible for data to be carried over the data plane unless signalling messages have already been exchanged over the control plane. Data being transferred over both channels – control and data - composes mobile traffic '*The data plane accounts for most traffic, typically over 95% of it*' [5], however, different patterns can be seen depending whether the device is being actively used or not as shown in Figure 5.

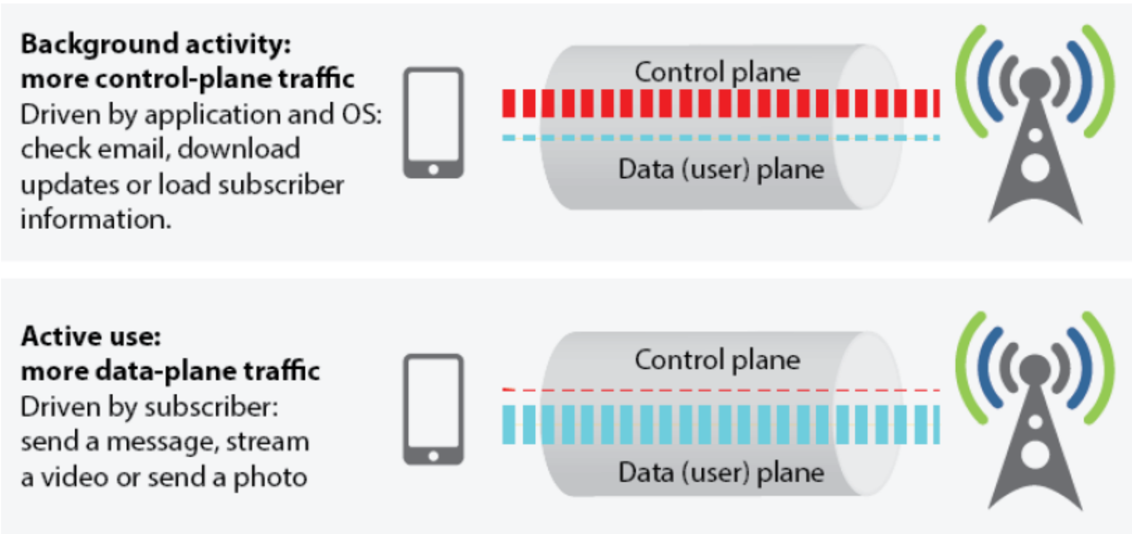


Figure 5. Majority of the traffic is for signalling when device is not under active use [5] P.5.

It is worth noting that for small short burst of user data, it is possible in 3G networks that the user data gets carried over RACH/FACH-channels, even though such channels were designed to carry signalling messages.

2.8 Radio Resource Control

Radio modem in a mobile device cannot be on all the time, because it would drain mobile phone battery and operator resources, therefore, radio modem can be on idle mode most of the time. In idle mode, the mobile device is still considered to be reachable and recognized by the network. A switch to fully operational mode happens once voice call or packet access is needed. In any case, there are some signalling messages being monitored all the time, for example, signal strength updates of surrounding cells.

There can be only one state for a connection in a given single mobile device. Alternating between states always requires special signalling messages and processing by network components to reserve and release resources. Such procedure is one essential element for this study in the efforts of detecting congestion.

2.8.1 Inactivity Timer and Battery Life

Inactivity timer is a time value which starts ticking once there is no uplink or downlink user data going on, for example, in case browsing a web page, typically there will be multiple HTTP requests and responses which will definitely make radio modem in a fully operational RRC state. Once the web page is displayed and no user traffic is ongoing, inactivity timer will start ticking. Afterwards there are two possibilities; it is either the user will click on some web link generating some more traffic which will reset the timer or the user will not click on any link letting the timer to expire. Once the timer expires, resources will be released and radio modem can demote to a lower state to safe energy and battery life. Timer value is set by network operator, where a bigger value will result in less signalling load, since one radio session will most likely serve bigger amount of user data, on the other hand, smaller timer value, will generate more signalling messages due to multiple radio connection establishment for the same amount and pattern of user data.

It is easy now to realize the trade-off between increasing the inactivity timer and network signalling load. Mobile manufactures prefer the smallest timer value possible, to increase their device’s battery life, while operators prefer a bigger value since connected time is not as big of a concern as signalling load. There is also a third element, which is user experience, since loading a web page while the radio already has packet session established is faster than waiting for the radio to establish packet session, then data transfer would start.

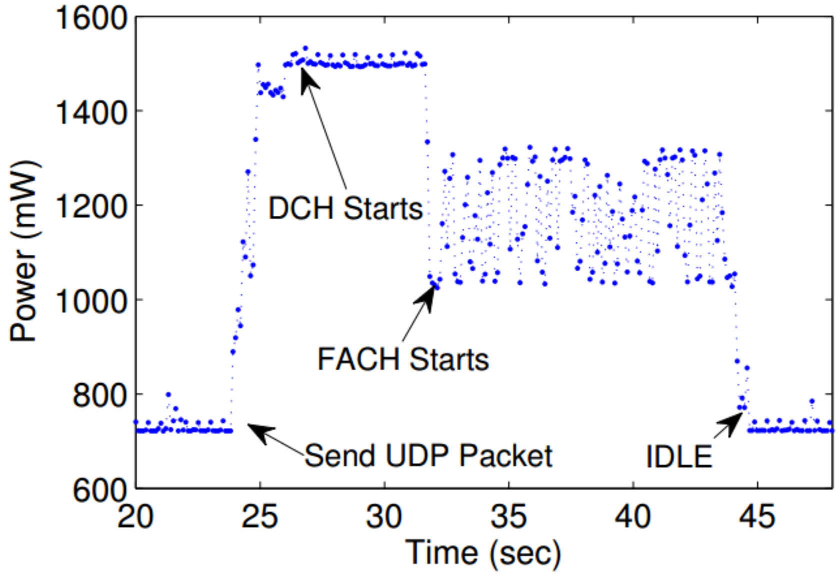


Figure 6. RRC states power consumption in UMTS [13].

The UDP packet seen in Figure 6 above had to face a delay in time for few seconds till the radio state promoted from IDLE to DCH, only then the UDP packet made it out of the mobile device, this delay is one essential parameter for congestion detection algorithm.

2.8.2 RRC States in UMTS

Once a mobile device is switched on, it will go through initial attach and when it is successfully camping on some nearby cell, RRC state will be on IDLE mode. Once there is incoming or outgoing packets there will be RRC Connection Establishment procedure, where it will promote the RRC state from IDLE to CELL_FACH or CELL_DCH depending on the traffic volume and network settings. The different RRC states in UMTS are shown in Figure 7.

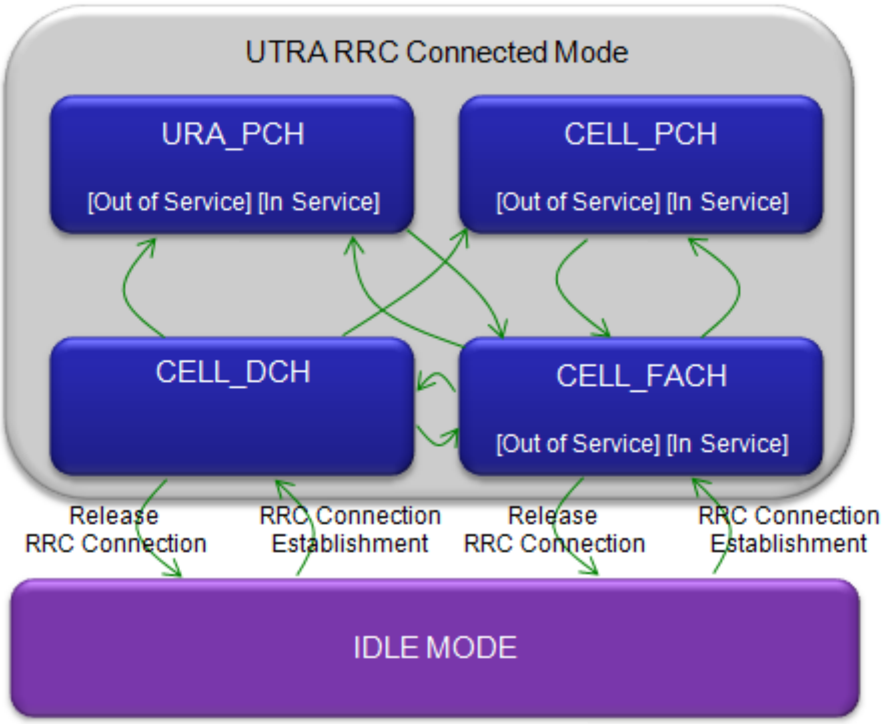


Figure 7. RRC states with green arrows showing possible promotions and demotions [7].

Once there are no more incoming or outgoing packets for some time –usually matter of seconds- there will be a state demotion from CELL_DCH or CELL_FACH to URA_PCH or CELL_PCH which are low power consumption states and no user data can be transferred, however, it is still faster to promote the state back to CELL_DCH or CELL_FACH than promoting from IDLE. If there is still no data activity for extended period of time –usually around half an hour- there will be demotion to IDLE.

The main difference between FACH and DCH is that the later one has a dedicated physical channel and transmit measurement reports, which help to get data transfer very reliably, therefore, HSPA variants are implemented to operate over DCH.

The above was a sort of mitigation for UMTS inactivity timers and their effect of battery life in 3GPP release8, where Fast Dormancy (FD) was introduced. FD will allow radio modem to ask for connection release SCRI message that will let the device demote to PCH instead of IDLE.

2.8.3 RRC States in LTE

There is noticeable complexity reduction in many aspects in LTE. RRC states are simplified to be two states, making promoting to connected state faster instead of the –mostly- gradual promotion in UMTS (see Figure 8).

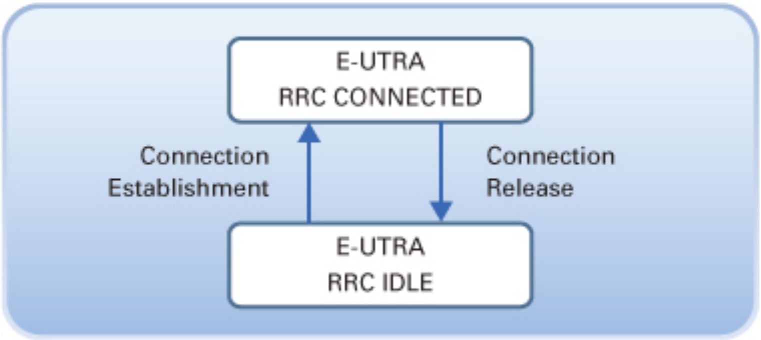


Figure 8. RRC states in LTE are only two RRC_Conncted and RRC_IDLE [9].

In order to simulate FD and the missing PCH state, there was increase focus on using DRX techniques namely Short DRX and Long DRX cycles to make power consumption during inactivity time more efficient. Looking at different operator settings, there is still no wide adaptation for DRX in LTE, which resulted in shorted battery life. Some might argue that eliminating RRC state CELL_FACH and the possibility for RACH/FACH to carry user data was not the best thing to do in LTE. Since in LTE there is no state where transferring relatively insignificance small burst of data is feasible without getting dedicated resources and higher level or energy consumption.

2.9 Signal Power and Noise Ratio

A mobile device includes a chip that always measures the incoming signal strength and background noise. It is the main measure for a mobile device to do a handover in favour of other cells with a stronger signal power. A weak signal power or high noise levels does not necessarily correlate with congestion. Under poor signal conditions a packet access call will either make it or not, while under congestion the packet call will make it under good signal conditions, however, the call will face delays.

2.10 Signalling Messages

Messages and updates are being exchanged over the control plane as long as mobile device is switched on; they handle all aspects for mobile connectivity. For simplicity sake, throughout this study, RRC states (IDLE, PCH, FACH) in 3G and (RRC_IDLE) in 4G are called 'LOW' RRC state, while, (DCH) and (RRC_CONNECTED) are called 'HIGH' state.

2.10.1 Connection Establishment

Connection establishment occurs, for example in UMTS, when RRC is on low state and there is incoming or outgoing traffic to mobile device (User Equipment), however, procedure is slightly different, depending on traffic direction.

A. Mobile device initiated connection

A typical case would be a client application, which is trying to reach its content provider, could be based on user interaction or not. Operating system's network stack will compose the required packets according to application's transport protocol. Packets will reach radio network interface where they will start to fill radio modem buffer. If there are only few packets or if they are small size, then they might get transferred using RACH uplink of CELL_FACH and that would not trigger full promotion to CELL_DCH. However, in most cases, packets have big payload which will fill the buffer instantly, in such case, radio modem will immediately start sending signalling messages as shown in the Figure 8.

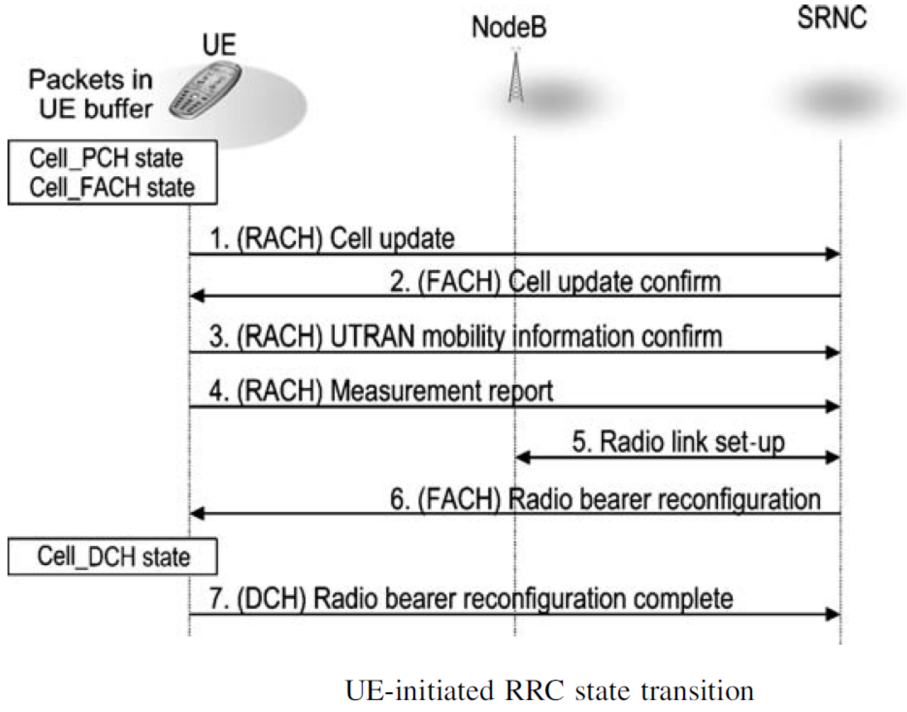


Figure 8. Signalling messages exchanged in 3G [6] p.168.

Packets will be transmitted once transition to DCH is completed. It is noticeable that RACH is always used for uplink (outgoing) messages and FACH is used for downlink (incoming) messages, both RACH and FACH are under CELL_FACH state.

B. Network initiated connection

A typical case would be a content provider pushing data to its client mobile application. Instant messaging mobile applications are the most common ones, for example, if someone sends a picture to his friend, the picture will be first uploaded to server side, which in turn will pass it to its intended destination. The picture packets will travel through internet routers, middle boxes and operator's core network till it reaches RNC where such large packet will fill up network side RNC's buffer. In such case of RNC full buffer, RNC will decide to promote DCH connection as illustrated Figure 9.

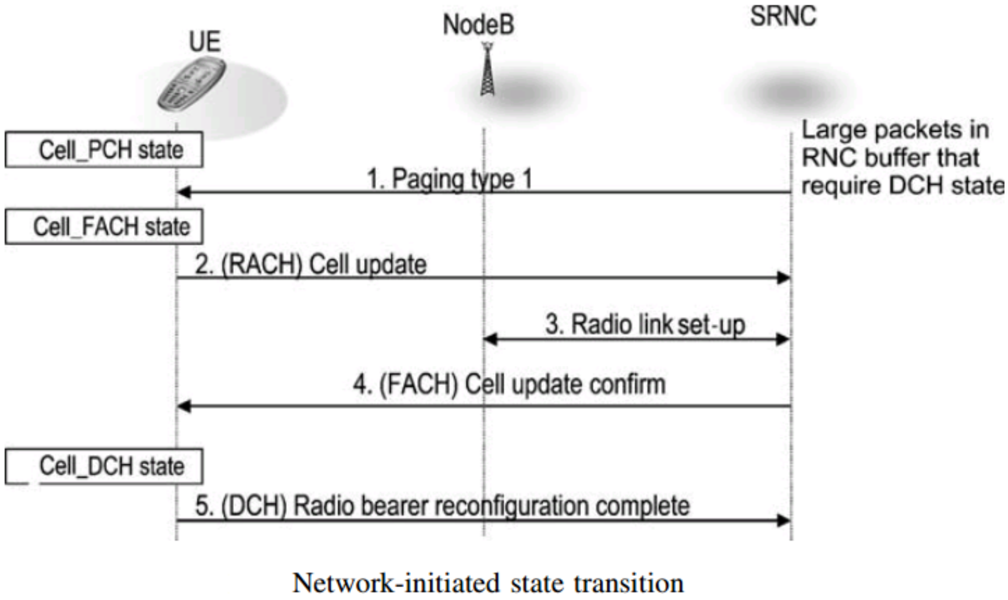


Figure 9. Signalling messages exchanged in 3G [6] p.168.

Once all packets carrying the picture gets transferred, RRC connection can demote to low state again after inactivity timer expiry, however, transport layer connection is maintained using keep-alive mechanism, which means that further incoming pictures and messages can find their way, and all what network side has to do is to page mobile device on the paging channel.

2.10.2 System Information Blocks

System Information Blocks (SIBs) contain parameters for the configuration of the common and shared physical channels to be used in connected mode.

Purpose of some SIB [10]:

MIB - Main index for system information. Contains scheduling information on SIBs and up to two scheduling blocks
SIB1 - Contains NAS information as well as information on timers for use in idle or connected mode.
SIB2 - Contains information on the URAs that are available. There can be up to 8 URAs in a cell.
SIB3 - Contains information on the cell selection and reselection parameters that the UE should use whilst in idle mode
SIB5 - Contains information on the common physical channels in the cell for a UE in idle mode.
SIB11 - Contains measurement control information for a UE in idle mode.
SIB12 - Contains measurement control information for a UE in connected mode.
SIB16 - Contains information on channel configuration (physical, transport and RB) to be stored in the UE for use during handover to UTRAN

SIB18 - Contains PLMN identities for neighbouring cells to be considered for use by a UE that is in either idle or connected mode

SIB3 includes reselection parameters that effect mobile device cell selection. Congestion can be on cell level and alternating between a congested cell and a normally functional cell will definitely affect any tool that is trying to detected congestion.

2.11 Mobile Data Connectivity in Practice

Modern mobile operating systems offer some means to check mobile data connectivity status, for example, in Android OS there is a ConnectivityManager and here is the best API offered to check connectivity:

```
NetworkInfo activeNetwork = connectivitmanager
.getNetworkInfo(ConnectivityManager.TYPE_MOBILE);
boolean isConnected = activeNetwork.isConnected();
```

NetworkInfo reference [11]

Quoting from (isConnected) method description that it “Indicates whether network connectivity exists and it is possible to establish connections and pass data”, however, this does not mean that the data will reach its destination server, as there could be congestion in UTRAN or in CN. On the other hand, iOS provides a slightly better approach with its Reachability API, where they test sending IP packets to a well-known and defined host - www.apple.com by default.

However, neither of the most used mobile operating systems Android and iOS, offers an easy to fetch information about network health, even thought they have access to the traffic for all the applications. That leaves the app developer to implement own testing with some server, for the pure purpose of knowing how good the network connectivity is. Such method will always be related to application own traffic. On the other hand, the operating system can see the combined traffic of all the applications, which means more knowledge can be obtained from such data. This study recommends that mobile operating systems should share the knowledge about connectivity conditions with all the mobile applications that are interested to know it.

2.12 Typical Mobile Traffic Types

Nowadays, mobile traffic of many mobile applications can go under one of the following categories according to their connectivity demands:

- Always connected: such applications live and breath on connectivity, their first task is to stay connected to their server, for example, Google services which is installed in almost every Android OS likes to keep a connection to Google's servers all the time and to keep that connection alive, there it sends a TCP packet every twenty minutes. Chatting applications also go under this category, for example, Viber application for instant messaging and voice calls, must maintain a connection so the incoming messages arrive without delay, of course, to achieve that a keep alive packet is sent every ten minutes.

- Semi connected: for those applications, staying connected is not vital for their functionality, weather applications can connected every now and then to get latest weather reports. Some other applications, needs to sync the latest offers and upload some data only when WIFI is active. There is no need for keep alive since the connection can be gracefully closed once the data exchange is done.

- Connected on demand: internet browser makes good example in this category where it is connecting only when there is a demand and request by the user. Which means that there is no need for a long lasting connection.

One important consideration is that mobile traffic is moving away from HTTP. Traditionally, HTTP has been known to be the internet language. HTTP is just strings streamed over TCP and those strings have special meaning for a browser. The browser can translate those strings into shapes and well-formatted text. However, in the recent years mobile traffic is shifting noticeably away from HTTP, while chatting applications are taking over with their custom protocols over TCP or UDP. Even lesser time is spent on web browsing over the small mobile screen, and more time is spent in instant messaging applications.

2.13 Effect of Keep-alive Mechanism on Networks

The typical HTTP traffic can be considered network friendly, since in its basic form the connection is closed as soon as HTTP documents and resources are downloaded. However, there are many approaches where they use HTTP for a long lasting tasks and employs some keep alive mechanism, in addition to the always-connected applications which have their own keep alive mechanism going on. The reason behind the keep-alive mechanism is that the connection would be broken without them. The reason is that router and switches have limited hardware resources and cannot keep routing tables and information about all the connections going through them, so they start to drop the old connections in favour of new ones, unless a packet goes though the old connection, which make the connection gain priority again, as it is considered to be still active and needed. That is why mobile applications wishing to keep their connection alive will have to keep sending keep-alive packets typically with very small payload just to prevent the connection information from being dropped in some router or switch.

It is easy to imagine the effect of millions of keep-alive packets going at specific times on the operator network. The pressure is greater on the Radio Access (RAN) than on Core Network (CN), since there are much more signalling and computer resources consumed to promote the radio connection in case it was idle than to forward the packet through CN routers and switches. It is worth to mention that the pressure on the RAN would be much smaller if the radio was already promoted and in active state, that is why Android in version Lollipop introduced new API to let applications know about the good moment to transmit packets, since the radio is already active.

```
ConnectivityManager. isDefaultNetworkActive ()
```

> Return whether the data network is currently active. An active network means that it is currently in a high power state for performing data transmission. On some types of networks, it may be expensive to move and stay in such a state, so it is more power efficient to batch network traffic together when the radio is already in this state. This method tells you whether right now is currently a good time to initiate network traffic, as the network is already active.[12]

This will ease the problem but it will not make a noticeable difference until it is widely adopted.

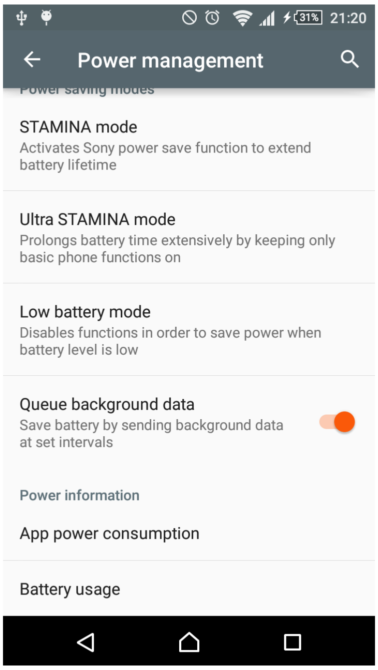


Figure 10. ‘Queue background data’ option in Sony Android

Sony mobile has customized their Android ROMs to include a traffic shaping feature that forces background data and keep-alive packets to be delayed and bundled together (see Figure 10). This method might sounds like a good idea, however, it is prone to break applications functionality since most applications have predefined timeouts. In case Sony power management agent delayed a packet more than the predefined value, the app would think that it lost connectivity, which force a more harmful, and aggressive retry mechanism.

The only way for the operator to cope with the problem is to install and upgrade hardware to handle the load. Deploying microcells (less than two kilometres) and picocells (less than 200 meters) is targeted to ease and distribute the load.

2.14 Mobile Traffic Congestion

Mobile traffic goes through radio wireless element and network element. Network congestion is well known issue and there are many methods to identify it. Mobile traffic is facing such network congestions as well, however, there is another type of congestion that is unique only to mobile traffic. Radio access congestion strikes early on before any network or routers, it even accrues before any packets leave the device.

Most of commonly used protocols incorporate some kind of algorithm to detect and deal with network congestion. Ethernet, for example, employs exponential back-off which prevent frames collision by retransmitting the frame from each host at random timings in range of milliseconds. The famous TCP has a set of techniques under its congestion-avoidance algorithm, namely the ‘slow-start’ and ‘congestion window’. They work together to limit the number of packets that has been sent and did not get acknowledged.

On the other hand, there is not as much of advanced algorithms and methods to detect radio access congestion. What is currently in operating is Connection Admission Control (CAC) algorithm, which insures a predefined level of Quality of Service (QoS) for a number of connections and if the number of connections exceeds the bandwidth available, the new connections will get rejected. A connection for CAC could be voice call via circuit switching or a video downloaded via packet switching, this means that at the nodeB and RNC level, they can be under huge load and CAC never kicks in or interfere to do anything. In such cases the nodeB or/and RNC can send RRC message ‘connection reject’ when they are running low on CPU and other resource, which is typically a result of heavy signalling load.

This study focuses on detecting the congestion in nodeB/RNC before reaching the critical level where they start to reject packet call establishments, while congestion in CN is out of the scope.

3 Targets and implementations

One could do a lot to optimize how IP packets are transmitted over radio signals; however, this study focuses on finding a way to detected congestion in packet access within UTRAN or E-UTRAN. The congestion detection algorithm lives in mobile device and takes ‘samples’ and other measurements as inputs. There are also parameters that can be changed to tweak its detection sensitivity.

In order to verify and collect data for analysis, an Android implementation of the algorithm was developed, in addition to server side software to store and to present algorithm internal calculations in real-time.

3.1 Congestion Recognition Algorithm Targeted Features

In order to leverage congestion recognition algorithm (CRA) value, the following properties were set as goals:

- Independent: once an implementation for this algorithm is operating on some mobile devices, it is not allowed for any running instance to assist by sharing information with another instance. While it seems greatly beneficial if inter-communication were allowed, it would be ironic for a solution that is trying to ease and help congested network to make some connections to gather information. It is not even guaranteed that a connection would be successful under a congested network. It would be a critical failure point if the algorithm is relying on some input from a remote resource, hence, all data and inputs must be collected locally. This implies that each instance of the algorithm is operating independently and taking its own decisions, totally isolated from other instances, servers and network health providers.

- Real time: most of the algorithm’s operations must be going on in real-time, for example, sample collections, RRC state tracking and making a final decision to block a portion of background traffic. However, log uploading and similar non-urgent functions should be deferred to more favourable conditions, such as, device is in charging mode.

- Based on user equipment: it would be a showstopper if there were a need for network side UTRAN to have some special support for this solution to work. It is well known that pushing some feature or request ahead needs a big player in the communication industry and it takes years till it is part of a next release specification. That is the reason why, the solution in this study can be fully run on mobile device only.

- Runs on all chipsets: radio modem chipsets have a variety of debugging information that can increase algorithm accuracy. However, the algorithm should be able to function without any chipset dependency. Such additional input can be decided on during implementation according to the use case, device, operating system and chipset. Qualcomm makes the most commonly used chipset out there. While it is mostly closed source, they provide Qualcomm eXtensible Diagnostic Monitor (QXDM) where an extensive volume of data is available, for example, all RRC messages can be collected as seen in Figure 11.

Figure 11. Example of logs generated by QXDM

The red highlighting in the above figure, shows the exact signalling message being exchanged to establish and teardown a connection.

- Adjustable Sensitivity Parameters: there could be use cases where it is preferred to tweak how sensitive the algorithm is in detecting congestion. For example, if the use case is to measure user experience then tweaking sensitivity settings to be more aggressive will generate reports around any turbulence in packet access.

The mentioned goals mean fewer restrictions on where the algorithm can run. It is feeding on readily available information and bringing great added value in return.

3.2 Sample Definition

A mobile device sends and receives packet traffic frequently; such packets relation with radio modem state can expose the following possibilities:

Radio state / traffic direction	Low state	High state
Incoming	A	B
Outgoing	C	D

Possibilities 'B' and 'D' are not useful for CRA, since it is focused on detecting congestion in RAN or cell. There are some other tools for detecting problems in CN where the focus is on the traffic while the radio is already on high state.

Possibilities 'A' and 'C' are candidates for sampling; however, it is only possibility 'C' where CRA can take a sample measurement, because it can get the packet timestamp once it is processed by OS/Kernel, while in case 'A' the timestamp of when the packet has reached RNC, is impossible for CRA to know, since it operates in the mobile device.

The order of events that allow the transition from idle mode to connected mode is shown in Figure 12.

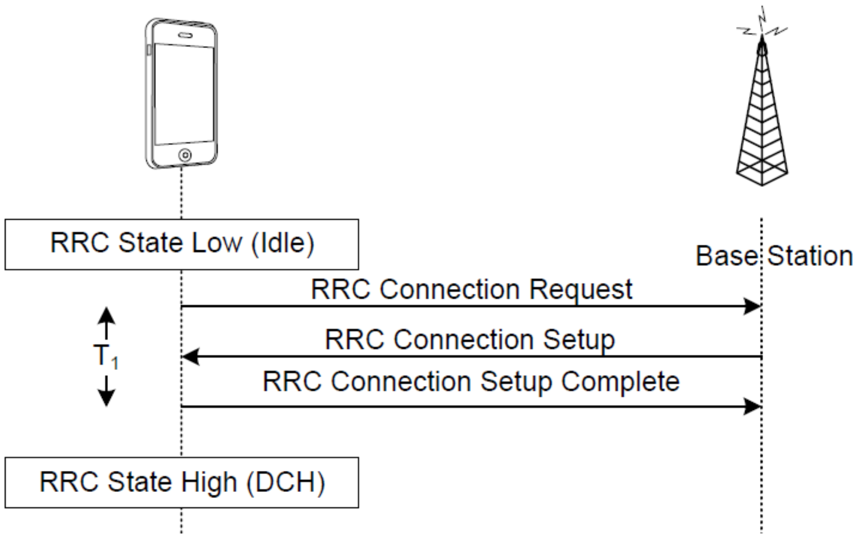


Figure 12. Possibility ‘C’ value is T1. [15]

Simply put, a sample is the time duration (T1 as in Figure 12), which is the difference between the time stamp of a request for packet access and the time stamp of when the packet access is actually granted.

3.3 Congestion Recognition Algorithm Inputs

In order to get CRA working, the following inputs and requirements must be met:

- Intercepting the traffic or generating it: the time stamp when the traffic was generated is needed for the sample calculations. The ideal way is to intercept the traffic that is normally transmitted while the user is browsing the internet and enjoying packet access. Intercepting the traffic can be done using (iptables) where some (NAT) rules can tunnel the traffic to local software where it acts like a proxy. Another alternative to achieve the same thing is to implement fake VPN client. However, if intercepting the traffic is not possible due to lack of permissions or for other technical limitation of the hosting platform, then a simple function can be integrated to generate some traffic and in that case getting the timestamp of the own generated traffic is pretty easy.

- Cell-id and location area code: all samples measured are associated with their respective CID and LAC. This is needed so the algorithm will know it if facing a RAN level congestion or only single level congestion, it is also good to know if some samples are higher or lower in value only under that cell. All those values will be included in the aftermath reports. Another benefit is that the congestion detection algorithm can notice if the cell id is changing fast which means that the mobile device is on the move and a lot of handover is happening. This helps the logic to avoid some creating a Potential Congestion Case (PCC) and wait till it can collect a fixed number of samples when the mobile device is not on the move, that fixed number is part of the parameters which can be tweaked. The raw information about LAC and CIDs of current and neighbouring cells is usually easily accessed without a trouble, it might need to ask for a permission, but it is easily obtained in the most common mobile operating systems.

- Signal strength: it is easy value to obtain for the currently camped on cell. Under bad signal strength the algorithm will be more doubtful about its decision, since a bad reception might be the reason for the abnormal and extreme values.

One of the beneficial features that CRA offers is to have few requirements and inputs. It is well known that more requirements and inputs may restrict the algorithm implementer from deploying it to a wider set of devices or operating systems.

3.4 Congestion Recognition Algorithm Components

There are multiple sub components and logical units working together to detect congestion. Figure 13 shows an overview:

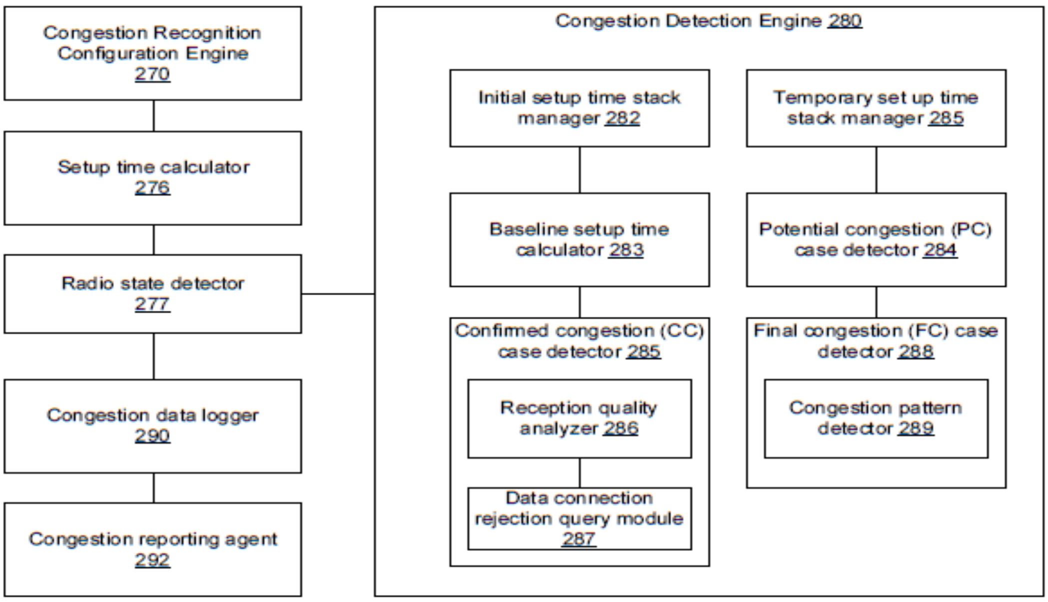


Figure 13. CRA components overview [15].

More detailed information covering each component function is provided in the following sections.

3.4.1 Configuration Engine

Here are all the parameters and configuration values that affects CRA functionality and decision-making:

- Setup time standard deviation allowance (st_std): will allow us to set how aggressive the logic should be in making a Potential Congestion Case (PCC), zero means most aggressive.

- Number of confirmed congestion cases (num_ccc): will allow us to set how aggressive the logic should be in triggering the Positive Congestion Decision (PCD), according to the number of Confirmed Congestion Case (CCC).

- Size of Setup Time records (st_stack): is like the logic memory, and how quickly the logic can adapt to another area setup time, smaller number means shorter memory.

- SNR normal values range (snr_rng) for RSCP value: This range is needed while deciding on each PCC. Example of values for UMTS:

RSCP (Signal power)	SNR (Signal-to-noise ratio)
-50...-70	0...-5
-70...-85	-3...-7
-85...-95	-5...-10
-95...-105	-7...-14
-105...-115	-9...-16
-115...less	-11...-18

- Number of cells to trigger (pcd_trg): how many cells must exceed the num_ccc (Number of confirmed congestion cases) in order to trigger PCD (Positive Congestion Decision). If the number is bigger than one, it means CRA will target congestions beyond one cell scope; for example, congestion can be at RNC level, because confirmed congestion cases are coming from more than one cell. However, if the number is set to one, then CCC coming from only one cell is enough to trigger PCD.

There are some elements that cannot be parameterized, such as differences between network operator infrastructure hardware. For example, the performance between Nokia and Huawei equipment is not exactly the same. This challenge is solved by adaptation feature of the algorithm.

3.4.2 Setup Time Calculator

The setup time calculator measures setup time for establishing a connection with a base station in the radio access network. The setup time is determined or measured as the time elapsed between the detection of a data request that requires a radio connection (or a radio turn on request) and transition of the radio state to a connected state from idle state in some implementations (i.e., RRC high timestamp - request time stamp during RRC low or idle) as seen in Figure 12. The radio state information can be determined or obtained from the radio state detector 277 as seen in Figure 13, for example, according to exact implementations, the setup time can be measured based on a radio access bearer setup time, measured as a time difference between transition to high RRC state timestamp and a request timestamp.

During a radio bearer reconfiguration procedure, a radio bearer reconfiguration message is sent by the network to a mobile device, and the mobile device acknowledges the receipt of the message by sending a radio bearer reconfiguration complete message to the network.

3.4.3 Congestion Detection Engine

In the engine resides the core logic, the following points explains how to it can activate its self and how different components analyse the emerging data:

- The initial setup time stack manager 282 of the congestion detection engine 280 as seen in figure 13, can aggregate a predetermined number of setup time samples (e.g., 20 samples or another number of samples based on st_stack), until the stack is full. When the stack is full, the initial setup time stack manager 282 can activate the logic for detecting potential congestion, the flowchart for activation can be seen in Figure 14.

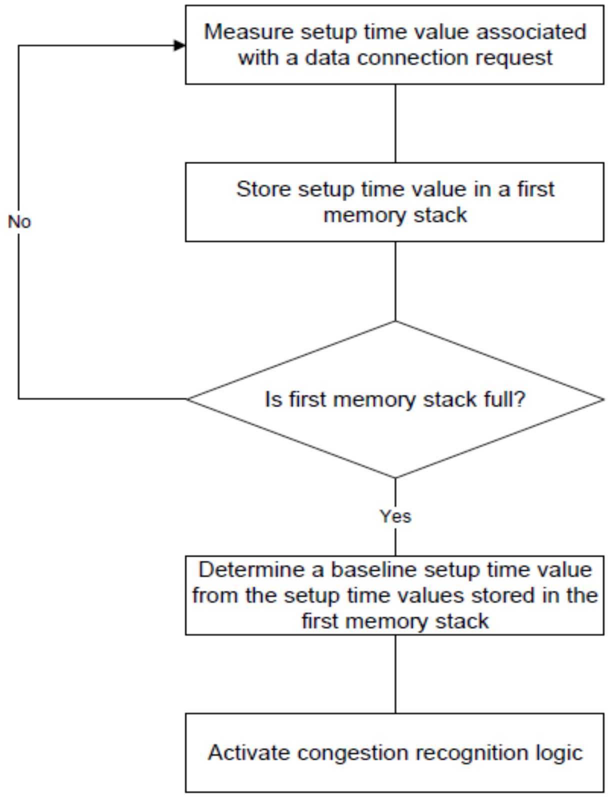


Figure 14. Flowchart showing CRA activation [15]

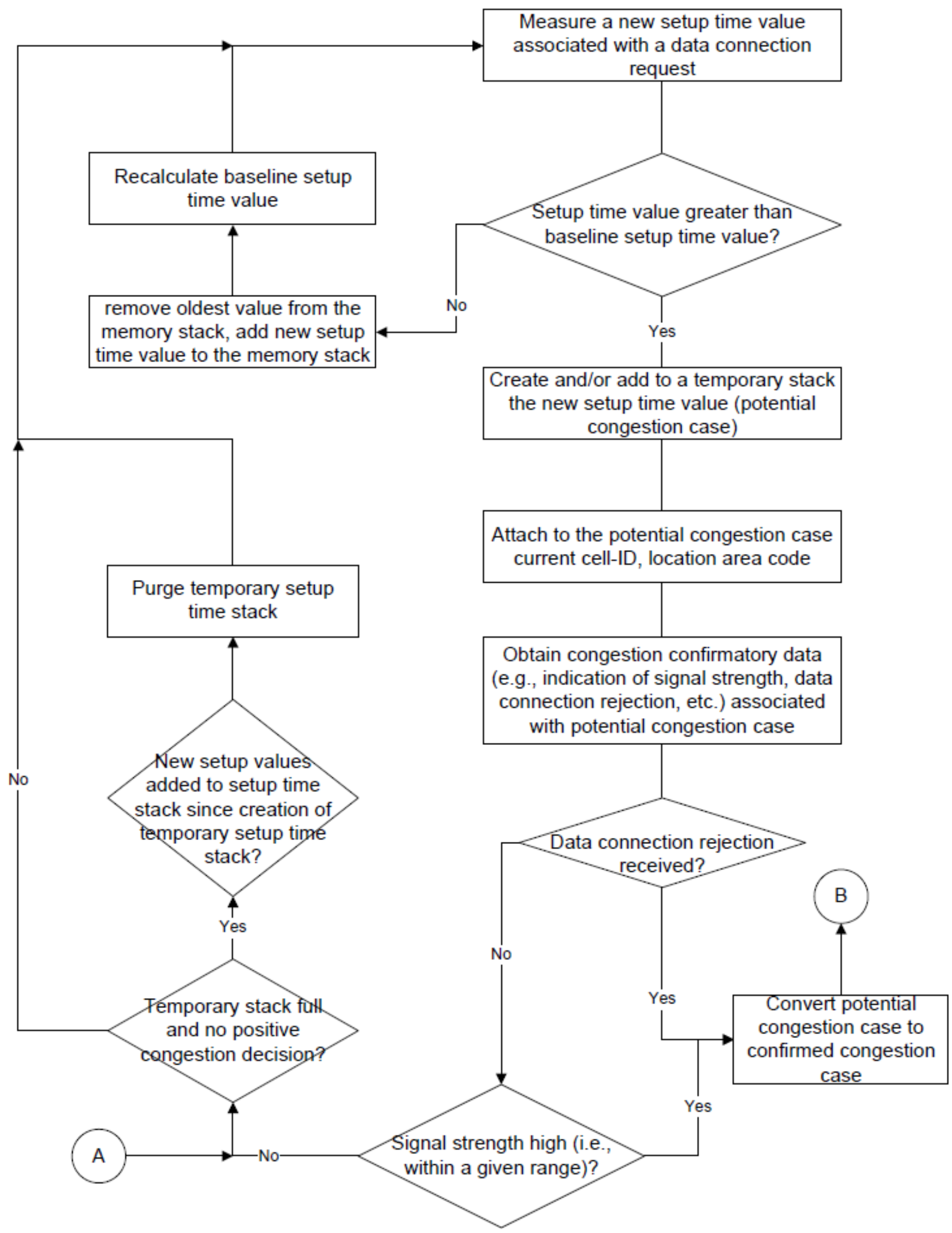
- The baseline setup time calculator 283 as seen in Figure 13 can be triggered by initial setup time stack manager 282 to calculate a baseline or reference setup time from the sample of setup times collected by the initial setup time stack manager 282. The baseline is calculated as the sum of the average or mean of the setup times in the initial stack, the standard deviation of the setup times in the initial stack and the setup time standard deviation allowance (**st_std**). The baseline can be determined using a variation of the method above, or any other statistical method in other implementations. The baseline setup time calculator 283 can be triggered to update its calculation of baseline every time a new set-up time value is measured by the setup time calculator module 276.

- The potential congestion case (PCC) detector 284 as seen in Figure 13, can be triggered by the activation of the congestion detection logic when the initial set-up time stack is full. The potential congestion case detector 284 detects a potential case of congestion by detecting an increase in setup time values compared to the baseline. The setup time values that are longer than the baseline are stored in a temporary stack of the same size as the initial stack by the temporary setup time stack manager 285. The setup time values below the baseline replace the oldest values in the initial stack (via the initial setup time stack manager 282). In one implementation, the potential congestion case detector 284 can acquire cell-ID or other base station identifier information and/or location area code for each potential congestion case detected. In one implementation, the cell-ID and/or location area code may be obtained using Attention (AT) commands used for controlling a device modem. For example, AT+CREG command returns cell-ID and location area code.

- The confirmed congestion case detector 285 can analyse the potential congestion cases and determine whether the potential congestion cases should be promoted to confirmed congestion cases. In order to detect confirmed congestion cases from potential congestion cases, the modem of the mobile device may be queried for reception quality data via the reception quality analyser 286, for example. In one implementation, using AT+CSQ command, received signal strength indicator (RSSI) value, which can be mapped to signal condition (e.g., marginal, OK, good, excellent or the like), can be determined. Other reception quality data that can be queried include, for example, received signal code power (RSCP) and ratio of received energy per chip (Ec/Io). Depending on the implementation, the modem may be queried for any RRC rejection messages from the base station by the data connection rejection query module 287, for example.

- The final or positive congestion case detector 288 can evaluate the confirmed congestion cases using the attached location area codes, cell IDs and other parameters (e.g., **num_ccc** and **pcd_trg**) to determine and/or verify whether the network is congested. In one implementation, the congestion pattern detector 289 can examine the cell-IDs and location area codes attached to the confirmed congestion cases to determine whether the confirmed congestion cases are concentrated on a few specific cell-IDs or are distributed over many cell-IDs and/or over multiple location area codes. This pattern of cell-IDs and/or location area codes associated with confirmed congestion cases can provide an indication to the final congestion detector 288 that the mobile device is in motion, and the confirmed congestion cases cannot be reliably used to determine the presence of network congestion. For example, if the analysis of the congestion pattern indicates that a large number of confirmed congestion cases are concentrated on a one or two cells, the final congestion case detector 288 can make a positive or final congestion decision. By way of another example, if the pattern of the confirmed congestion cases indicates cases associated with multiple cells belonging to different location area codes, the final congestion case detector can determine that the mobile device is in motion, and a final decision cannot be taken.

The congestion detection engine logic - after being activated - can be summarized in the following flowchart seen in Figure 15:



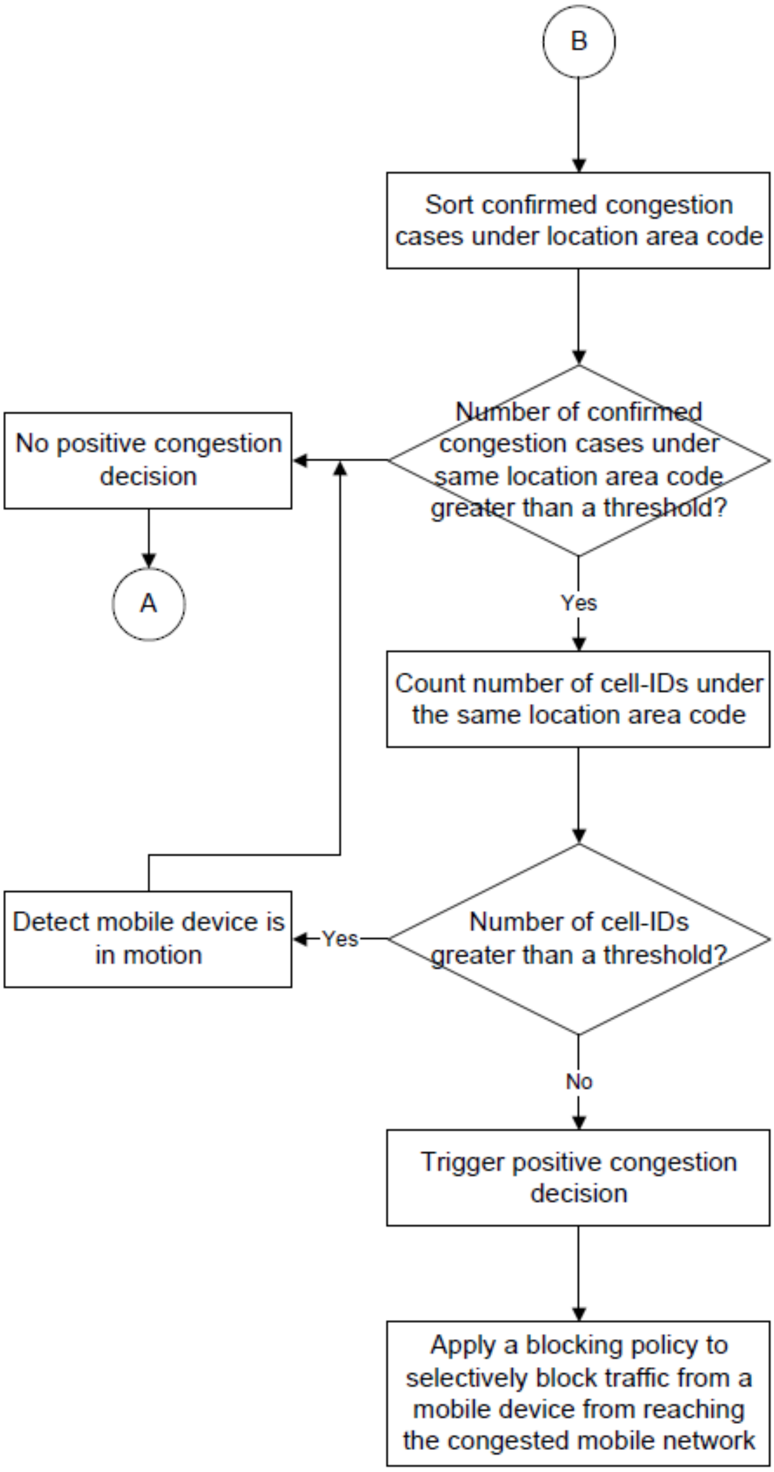


Figure 15. CRA logic flowchart [15]

After a final positive congestion decision has been triggered, a smart blocking policy can be applied. However, that is only one suggestion. Further or alternative actions can be taken depending on business needs, more on that is presented in the recommendation section of this study.

3.4.4 Congestion Data Logger

Congestion data logger logs all data related to congestion detection. For example, the congestion data logger 290 can log data request timestamps, radio turn on timestamps, setup times in association with corresponding cell-IDs and location area codes, reception quality measurements (e.g., RSCP, Ec/Io, RSSI, and the like), final congestion detection data (e.g., final congestion detection date, time, cell-IDs, location area code, network operator (e.g., Sonera, Elisa, Verizon, AT&T, etc.), and the like), configuration parameters and/or settings, device information.

3.4.5 Congestion Reporting Agent

The reporting agent uploads logged congestion data to the server-side proxy, the host server, and/or the log storage and processing service. The agent 292 may be configured to generate and send congestion reports to the LSPS or other remote entities periodically, or whenever a connection is available. In one implementation, the congestion reporting agent 292 can crate congestion reports using one or more templates.
Log uploading is trigged when a predefined number of logs or time limit has been reached, however, the logs patch has to wait for two conditions, first one is that the device has to be on charger in order not to effect battery life; the second condition is WiFi connection or free-riding on already established packet access radio connection, with the aim to avoid being responsible for imitation the radio connection.

3.4.6 Report Analysing Agent

All the report are handled in server side application, where they get plotted on a map (see Figure 16) showing how many CRA instances have reported congestion, the reports have information about Location Area Code ‘LAC’ and a list of connected cell-ids. CRA reports analyses has a critical role, where it serve as the last filter in the logic to eliminate false positives

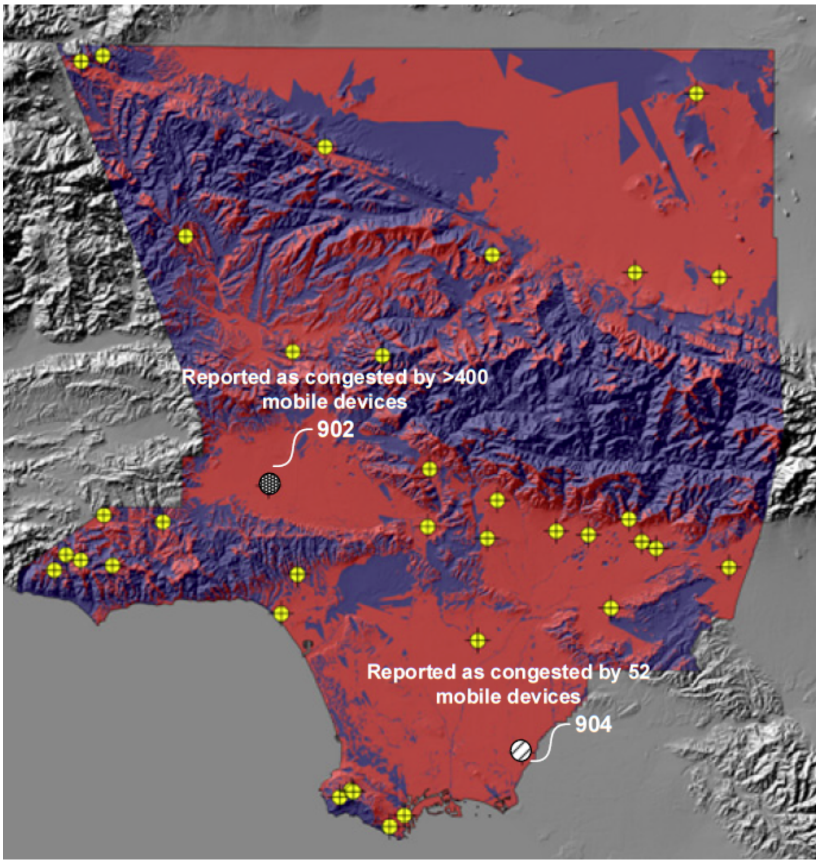


Figure 16. Reports plots on a map illustration [15]

This serves as final stage for filtering out false positives. The filtering could be done by human or some simple software, where congestion reports from few devices only can be ignored. On the other hand, if many congestion reports were coming from one specific location, then it is likely to be a correct indicator of a problem there.

3.5 Collecting Samples

In a production environment the optimal implementation of congestion recognition algorithm suggests that the samples and other inputs should be measured out of normally transmitted traffic. This way there won't be any overhead, but this also means that time stamp should be collected for each request going out of the mobile device. Usually that requires some level of intercepting the traffic or collecting data about it.

The other option would be to make a specialized application to generate and collect the samples, but that would not be as optimal and it would cause overhead, since there would be some traffic generated and bringing the radio up for the sake of collecting a sample. In order for the sample to qualify as per definition, the traffic must be initiated when the radio is on idle mode, so it is not possible to free ride the radio session that is already up. The sole advantage of this approach is that it can work out of the box and start working as soon as it is installed, therefore, no need for intercepting any traffic or any special permission. The frequency for taking a sample can be every twenty-minute at least to provide enough data for congestion recognition algorithm to learn and study what is normal and look for anomalies.

3.6 Android Implementation

In order to place congestion recognition algorithm into practice, an implementation has been developed on top of Android platform. The first challenge was in capturing the radio RRC state accurately, such data is not available within Android API. After doing some research around the problem, it seems that other researchers [11] are relying on packet dumps and power monitors plugged to a mobile phone. Combining both data sources to develop a module that is based on a timer to estimate dormancy timer value. Using the timer value it was possible to estimate when the RRC demotion would happen. Any new packet after the demotion is assumed to cause RRC promotion. Afterwards, the results were verified with help of power consumption monitor, since most of the RRC states have distinctive power consumption stamp as shown in Figure 6.
For the sake of this study, it was clear that any method of post processing will not be beneficial, since one of the main goals is to achieve real-time congestion detection and decision-making. Therefore, after spending considerable time searching over the web for a way where an android phone can access RRC state. The result was that many people were looking for the same thing, and there was no solution. However, it is possible because there is Samsung service app, which is able to read the RRC state in real time, as can been seen in Figure 17.

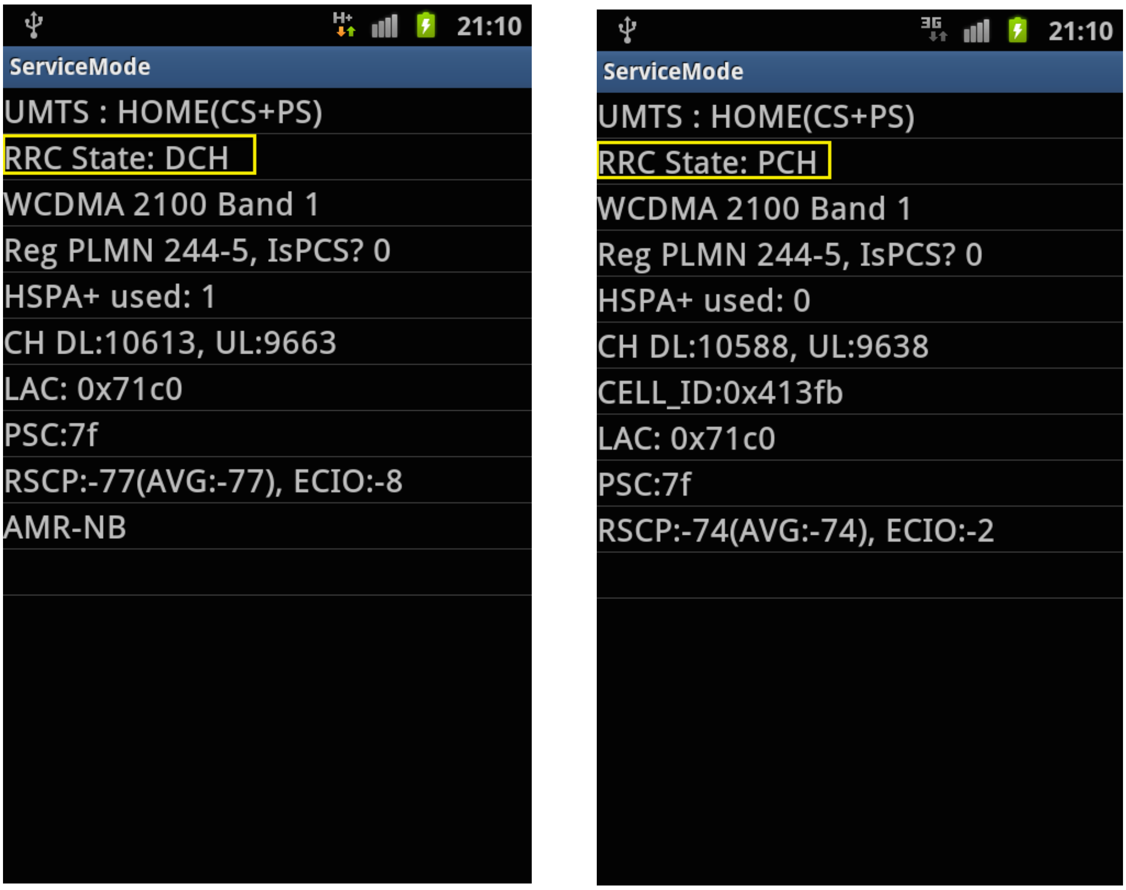


Figure 17. Samsung service app, accessed by dialling *#0011#

Of course, Samsung service app is closed source, and it is used by their engineers and is not meant for end user or developers. Therefore, as part of this study Android Radio Interface Layer (RIL) was investigated and an overview of the RIL stack is shown in Figure 18.

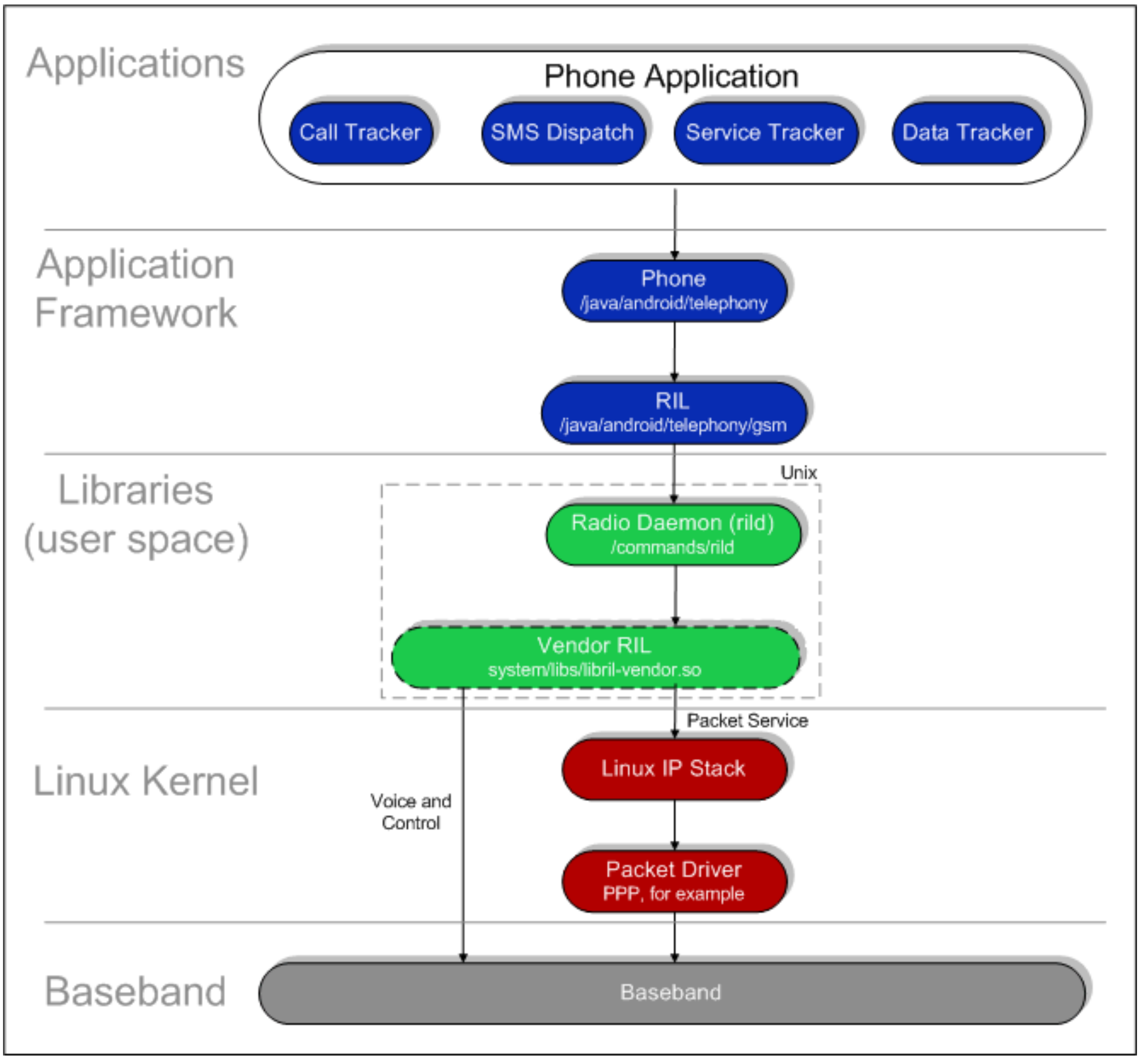


Figure 18. RIL stack [14]

Looking at RIL architect (Figure 18), there was a need to choose an intervention point, or in other words, at what level of the stack should the modification take place. The baseband definitely offers what is needed and more, but it lives in its own shell, own CPU and own memory. Hacking into the baseband chipset is difficult mission. Next comes Linux kernel, which is more realistic option, but still complicated. Going up in the stack, there are libraries, which are just made of blob of bytes and its always vendor or manufacturer specific. Application framework on the other hand is relatively easy to modify, so that was the path chosen. It is worth to mention that having root access in the mobile device is not enough to tamper with RIL messages, the need was to tamper with telephony process it self. In order to do that, the Android application being developed needs to be signed with system keys. Typically all system applications that comes preloaded with the phone are signed with system keys, such keys are well protected by their owners. The only option left is to build own custom android OS image as part of this study. Only that way, it is possible to acquire own system keys. Once the application is a signed system app, it can live together in telephony process, where it is allowed to communicate RIL messages. Speaking of which, RIL messages are split into two categories:

- Solicited Commands:

  They start with an activity or request generated by the user or the OS. A user can initiate a call or send SMS, which will result in generating a RIL request. The OS in the other hand generates RIL requests frequently, for example, to check for signal strength. Figure 19 is good example of solicited call flow.

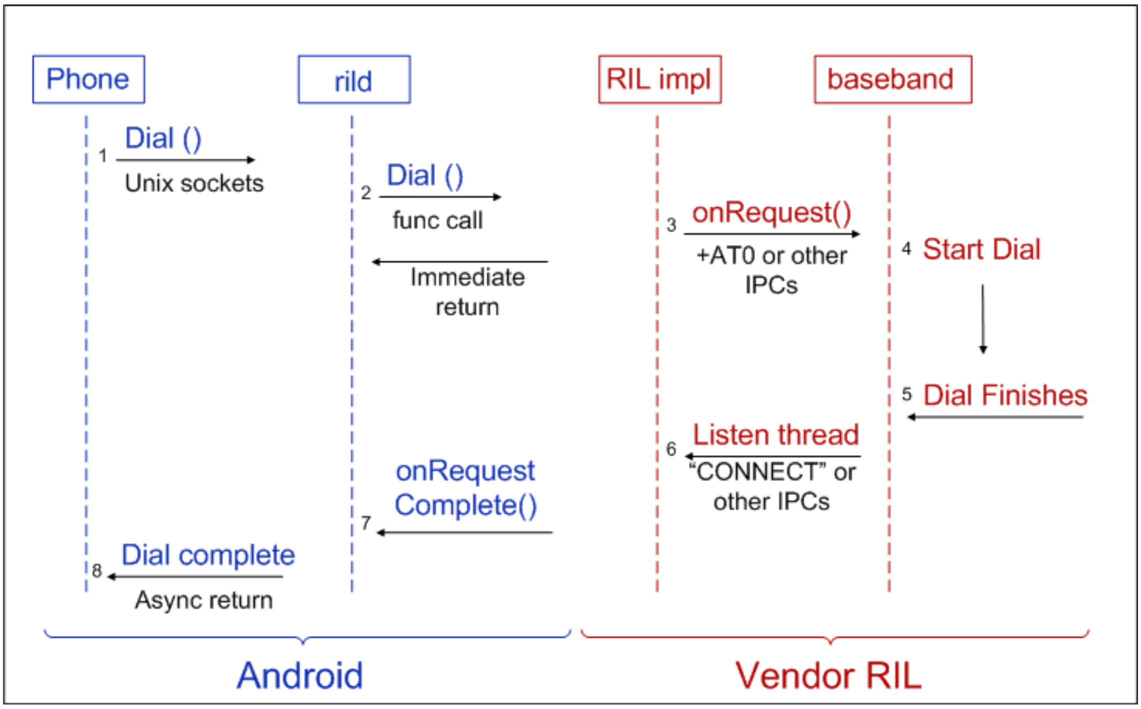


Figure 19.Diagram illustrates a solicited call in Android [14]

It is noticeable that the thread executing the Dial() function in (Figure 19) diagram will return immediately, where the native RIL implementation and the baseband firmware is taking over. The baseband firmware is working in SoC where it enjoys its own CPU and memory.Here is a list of most interesting RIL solicited requests:

RIL_REQUEST_GET_SIM_STATUS	RIL_REQUEST_ENTER_SIM_PIN
RIL_REQUEST_ENTER_SIM_PUK	RIL_REQUEST_CHANGE_SIM_PIN
RIL_REQUEST_DIAL	RIL_REQUEST_GET_IMSI

RIL_REQUEST_HANGUP	RIL_REQUEST_CONFERENCE
RIL_REQUEST_BASEBAND_VERSION	RIL_REQUEST_SIGNAL_STRENGTH
RIL_REQUEST_OPERATOR	RIL_REQUEST_RADIO_POWER
RIL_REQUEST_DTMF	RIL_REQUEST_SEND_SMS
RIL_REQUEST_SET_MUTE	RIL_REQUEST_WRITE_SMS_TO_SIM
RIL_REQUEST_OEM_HOOK_RAW	RIL_REQUEST_OEM_HOOK_STRINGS
RIL_REQUEST_SEND_USSD	RIL_REQUEST_GET_IMEI
RIL_REQUEST_SET_BAND_MODE	RIL_REQUEST_VOICE_RADIO_TECH
RIL_REQUEST_DEVICE_IDENTITY	RIL_REQUEST_QUERY_TTY_MODE

- Unsolicited Commands:

They start with activity initiated by the network or the baseband. The network can signal some RRC messages to the mobile device in case of an incoming call, which will be received firstly by the baseband where it will translate the RRC messages to RIL unsolicited commands, then they will be pushed forward up in the stack till it reaches the phone UI. Figure 20 holds an example of unsolicited call flow.

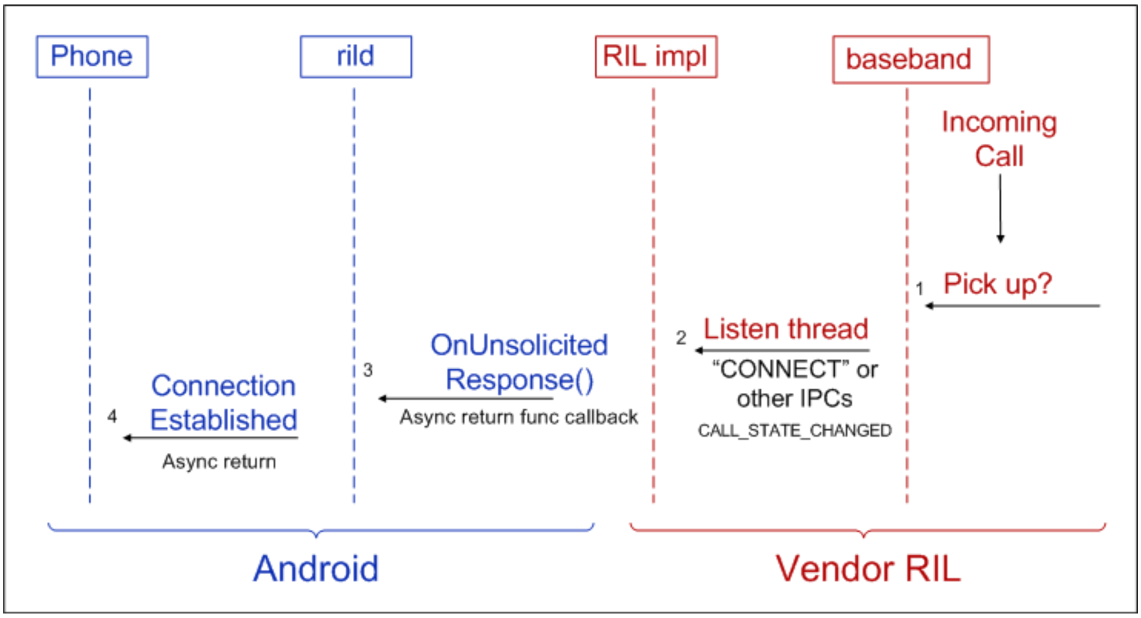


Figure 20. Diagram illustrates an unsolicited call in Android [14]

As seen in Figure 20 the incoming call triggered a series of events that is assuming that the user has accepted the call and the connection got established, otherwise, there would be different scenario if the call was rejected. In any case, RIL_UNSOL_CALL_RING will be used to promote the user the option to accept or reject the call.

Here is a list of most interesting RIL solicited requests:

RIL_UNSOL_RESPONSE_NEW_SMS	RIL_UNSOL_ON_USSD
RIL_UNSOL_SIGNAL_STRENGTH	RIL_UNSOL_RINGBACK_TONE
RIL_UNSOL_OEM_HOOK_RAW	RIL_UNSOL_CELL_INFO_LIST
RIL_UNSOL_RIL_CONNECTED	RIL_UNSOL_STK_SESSION_END
RIL_UNSOL_SIM_REFRESH	RIL_UNSOL_CALL_RING
RIL_UNSOL_SIM_SMS_STORAGE_FULL	RIL_UNSOL_ON_USSD_REQUEST
RIL_UNSOL_CDMA_INFO_REC	RIL_UNSOL_CDMA_CALL_WAITING
RIL_UNSOL_STK_EVENT_NOTIFY	RIL_UNSOL_STK_CALL_SETUP

Out of many RIL commands, it was discovered that Samsung service mode is using (RIL_UNSOL_OEM_HOOK_RAW) and (RIL_REQUEST_OEM_HOOK_RAW). The commands used were pin pointed by running the service mode app on RF monitor activity and then watch output of Logcat for radio, which can be accessed by the following command:

```
adb logcat -b radio
```

It is worth to note that radio log is not part of the main default logcat and cannot be accessed by simply applying filtering, since radio logging has its own buffers.

3.6.1 RRC State Broadcasting Service

The goal was to develop an Android service that can broadcast the RRC state in real-time where any app installed on the device can listen and make use of the information. This service must work as system app and live in the telephony process, that is why the code was placed for the service app next to other system applications sources, so the service application will get compiled and signed by the system.

The service code must replicate the way of communicating that Samsung service app is doing, so decompiling (SamsungServiceMode.apk) was necessary. It was not big surprise to find that they have heavy obfuscation, however, some useful code and values were recovered. Of course, those binary values were not human readable, but the aim was to replicate the communication regardless of what that actually is. It was found that some custom rom developers have been trying to put open source version of

Samsung service mode. The only useful file that was found in their source code repository, contained the following methods:

```
public static byte[] getEndServiceModeData(int modeType) {
        try {
            ByteArrayOutputStream baos =
            new ByteArrayOutputStream();
            DataOutputStream dos = new DataOutputStream(baos);
            dos.writeByte(OEM_SERVM_FUNCTAG);
            dos.writeByte(OEM_SM_END_MODE_MESSAGE);
            dos.writeShort(5);
            dos.writeByte(modeType);
            return baos.toByteArray();
        } catch (IOException e) {
            Log.e(TAG, "", e);
        }
        return null;
    }

    public static byte[] getPressKeyData(int keycode, int query) {
        try {
            ByteArrayOutputStream baos =
            new ByteArrayOutputStream();
            DataOutputStream dos = new DataOutputStream(baos);
            dos.writeByte(OEM_SERVM_FUNCTAG);
            dos.writeByte(OEM_SM_PROCESS_KEY_MESSAGE);
            dos.writeShort(6);
            dos.writeByte(keycode);
            dos.writeByte(query);
            return baos.toByteArray();
        } catch (IOException e) {
            Log.e(TAG, "", e);
        }
        return null;
    }
```

Code snippet to compose byte array. [16]

The next step was to write the code, which reads RRC value and broadcast it. Highlights of the code is provided, so anyone with minimum experience could develop such functionality.

At first, when developing an app that talks to the baseband, that code should be run in the same process as (phone), needless to mention, using Java reflection can't be useful in this case, since the (com.android.internal.telephony.Phone) object is in its own process. These XML flags in will force the service to run in the (phone) process:

```
<manifest android:sharedUserId="android.uid.phone" >
<application>
<service android:name=".RRCService" android:exported="true"
```

```
android:process="com.android.phone"  />
</application>

</manifest>
```

Thereafter, issuing RIL requests using the (phone) object is possible:

```
Phone mPhone = PhoneFactory.getDefaultPhone();
private void sendRequest(byte[] data, int id) {
        Message msg = mHandler.obtainMessage(id);
        mPhone.invokeOemRilRequestRaw(data, msg);
 }
```

Where data comes from (OemCommands.java) mentioned above. Once the answer arrives – in range of milliseconds – the strings are parsed to extract the RRC state, then only if the state changes from once state to another, for example, from FACH to DCH, then an Android intent is broadcasted announcing the new RRC state.

3.6.2 Congestion Recognition Mobile Application

Since the problem of getting RRC state in real-time is solved as explained in the last paragraph, it is now possible to turn the algorithm into code. The only practical addition that was made is to generate HTTP requests as soon as the radio goes idle. This helped to accelerate sample collection; in addition, the content of each request is holding information about the previous sample. Web application was also developed to provide real-time monitoring by processing the content of the HTTP requests, more about that in Real-time monitoring web application subsection.

The application implementation has an Android Service that sends HTTP requests as soon as the radio goes down. Of course that is an operator network nightmare since it is the most signalling resources consuming way and it can be considered a form of denial-of-service (DoS) if it was installed in a big number of mobile phones. However, this application is not published and the experiments using one mobile device will not have any noticeable effect.

The second component in the app is UI or activity where collecting samples can be seen in action (Figure 21).

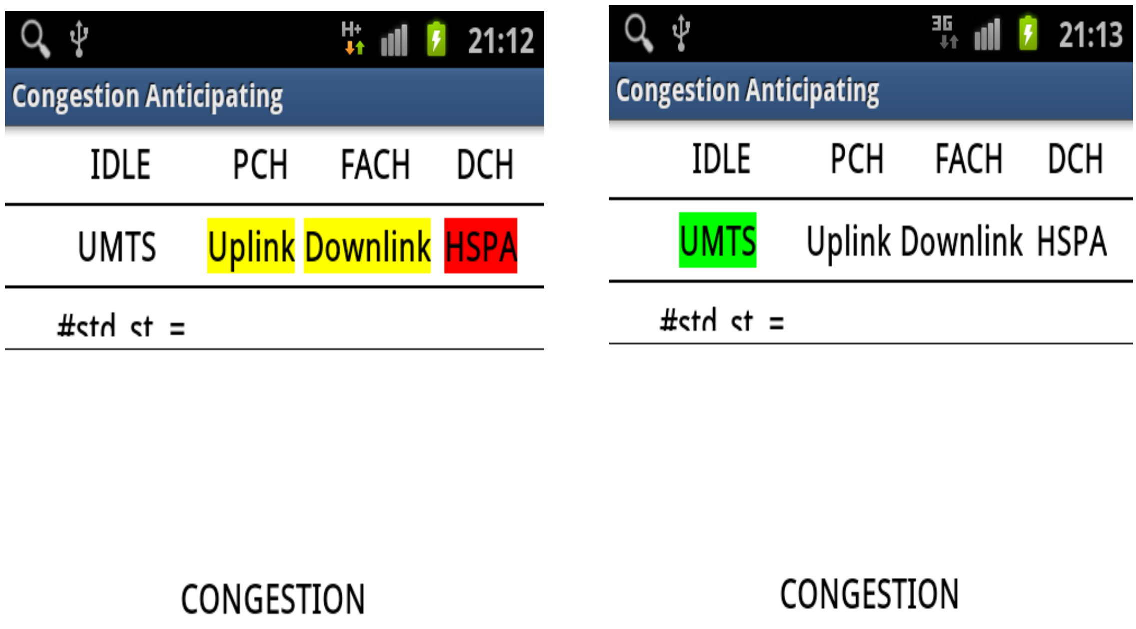


Figure 21. Android application interface

The first row has the four RRC states and it will highlight the corresponding RRC state according to broadcasts received by the previously developed ‘ RRC state broadcast service’. The second row shows the status of uplink, downlink, UMTS and HSPA, where such information is derived from Android’s API Telephony Manager.

There is clear correlation between the state reported by Android OS and the actual RRC state, it was found that when the OS report UMTS state and there is no downlink or uplink traffic that means RRC state is RRC_IDLE or PCH, while a UMTS state with some traffic means that RRC state must be FACH. The following table has the complete state mapping:

	UMTS	HSxPA
On-going traffic	FACH	RRC_DCH
No traffic	RRC_IDLE/ PCH/ URA_PCH	RRC_IDLE

The mapping can help any Android application to make a very accurate guess about RRC state on any Android ROM, without the need for root access or building own system image. This might help a lot of Android developers that are looking for a way to get

RRC state. The only drawback is that the mapping cannot tell if it is RRC_IDLE or PCH.

The congestion label in the middle will turn on once a final congestion case has been detected; following the CRA logic and decision flow as shown earlier.
Another modification was needed in order to insure that sample collection and measurements are as accurate as they can be. That modification took place in filtering table to drop any packet that does not belong to the Android app. The following iptables commands achieved the goal:

```
iptables -A OUTPUT -m owner --uid-owner
"+android.os.Process.myUid()+" -j ACCEPT // accepts all traffic
originating from own application
iptables -A OUTPUT -j DROP --dport 1:65500 //blocks all other traf-
fic
```

3.7 Real-time Monitoring Web Application

As part of this study, there was a need to develop a web application meant to show the congestion recognition algorithm internals in real time, as the Android congestion recognition mobile application is taking samples and posting them to the web application every few seconds. The web application can handle input from many mobile devices. The interface gives a list view of all operators and IMEI of mobile devices under that operator. It is then as easy as dragging that IMEI under specific operator and dropping it in the designated area, where a graph will appear showing latest samples values as they arrive from mobile application. The following graph (Figure 22) is a snapshot of the web interface.

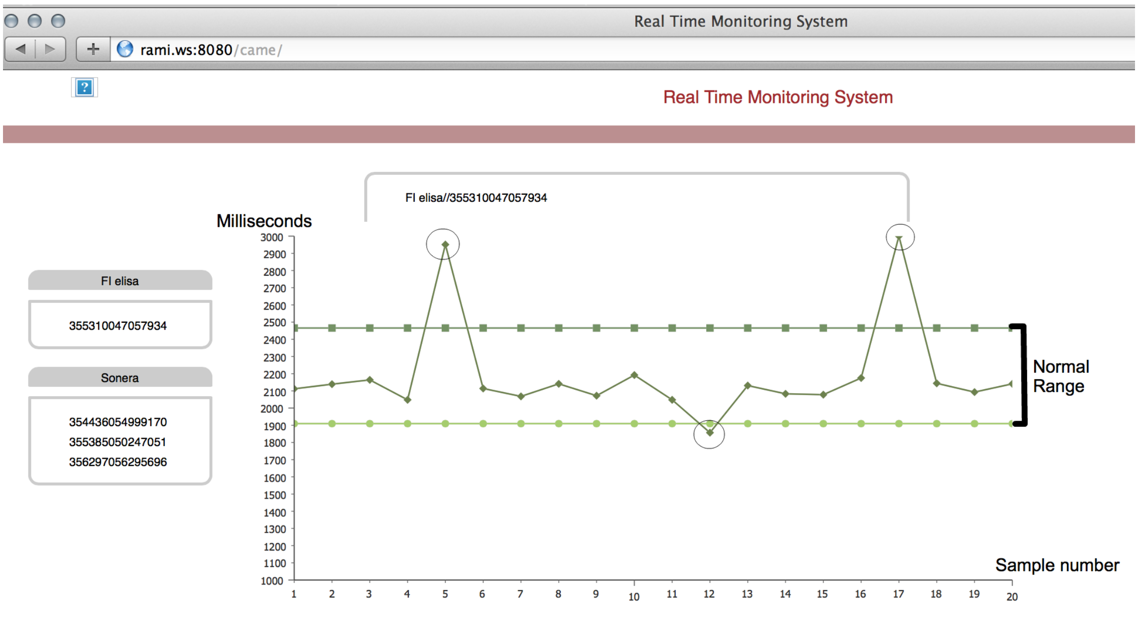


Figure 22. real-time monitoring of running Android CRA instance on Elisa

The graph and the list of devices updates in real-time without need to refresh the page, once a new CRA instance is installed and started communicating with the server, the list on the left will list the new device IMEI under the respective operator. After dragging and dropping one of the devices in the upper designated box, the graph will star drawing the latest twenty samples. According to the algorithm logic, the detection gets activated only after studying the base line, in order for the logic to know what is normal connection establishment time and what is abnormal. The normal range is simply the standard deviation boarders and any value that belong out of the range, it will be moved to the potential congestion cases stack, where the logic will try to make sense out of the situation if such abnormal values kept coming. Those spikes will be forgotten as the potential cases stack gets dropped if the baseline stack got full of normal and within the baseline range.

Another snapshot of the web interface (Figure 23) showing data points being collected while device is connected to DNA network.

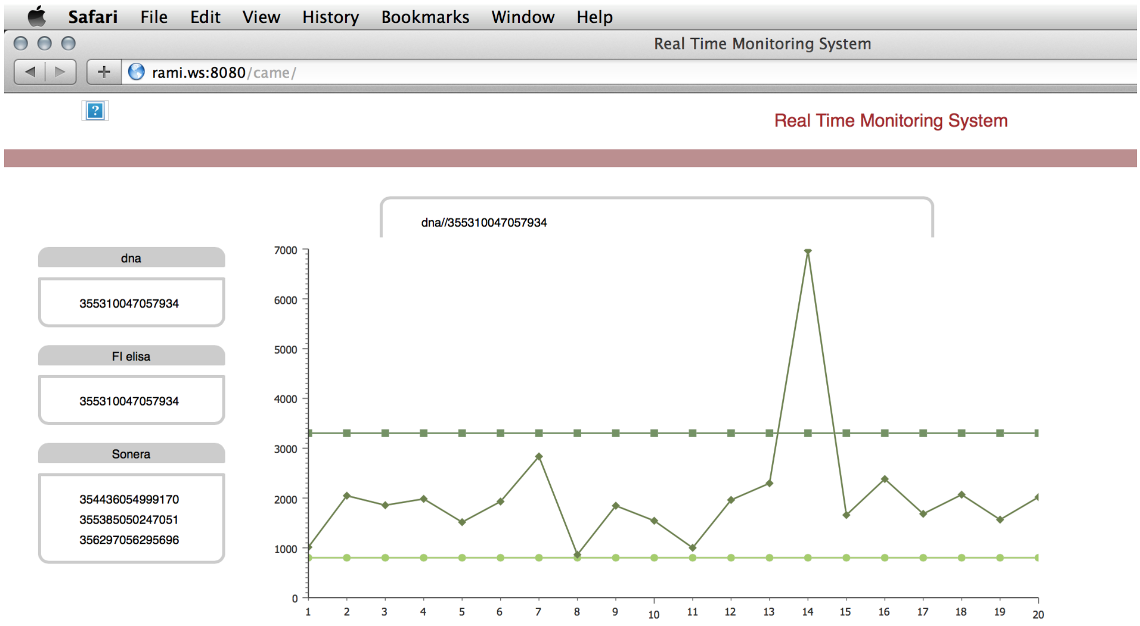


Figure 23. real-time monitoring of running Android CRA instance on DNA

It is interesting to see in Figure 23 how the same instance and same device but on different network showed more dispersion. For example, for a given twenty samples on Elisa network the values were around 1.9 to 2.5 seconds to establish a packet access session while on DNA, the values hovered in a bigger range of 0.9 to 3.4 seconds.

Regarding the technologies used and in ordered to achieve the live updating for the graph of the selected mobile device, and without the need to press browser 'Refresh page' button. After exploring the single page web applications, where all requests happen without reloading the page, and when a response comes, then only part of the page will be updated accordingly. Another approach was to push the response when there is a new data, instead of waiting for the client to check. The best way with the least overhead and latency is achieved by using a technology called WebSockets, where a TCP connection is maintained and server can easily push new data down the stream. Another benefit of WebSockets that there is no HTTP headers overhead, which usually is part of any HTTP request. However, in this study it was best to settled with more commonly used, better-supported and older technology called AJAX. It can easily manage the refresh rate of few seconds, which suits the needs here perfectly. The next step is to find a library that makes dealing with AJAX easy. After some research, DWR (Direct Web Remoting) was the best option. It was easy to integrate in the Java web application and it opens up the backend Java methods to be used in JavaScript. For example the following call (see Figure 24) is made possible by using DRW:

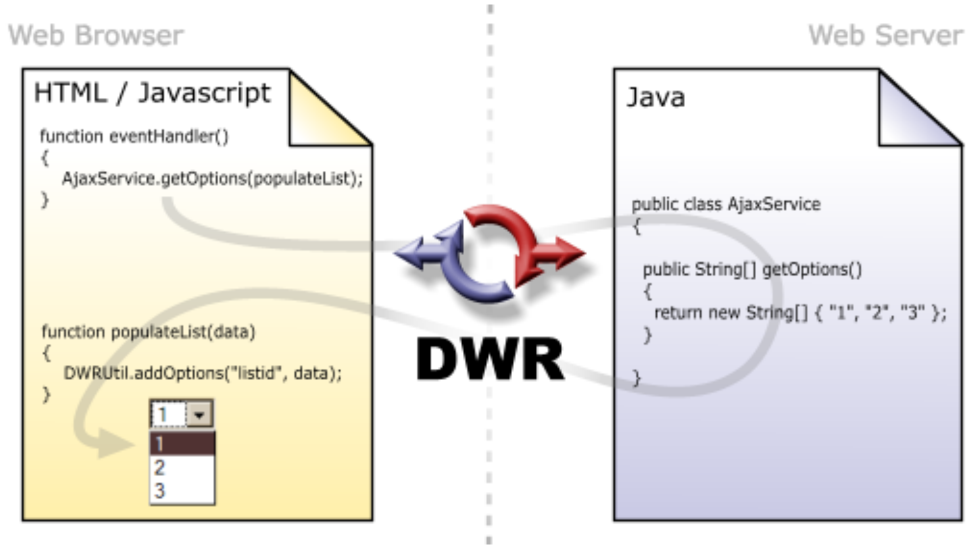


Figure 24. DWR workflow acting as bridge between server and browser. [17]

MySql was used to store data received from all the Android applications and Tomcat7 as web container running on Linux Virtual Private Server (VPS) with static public IPv4, which made it easy to point all clients to that public address. Dojo served as the JavaScript library to enable drag and drop functionality and to handle data visualization and drawing the graph.

Some parts of the congestion recognition algorithm were moved to the server side, while as per algorithm design all the logic must be contained in the client. The move of some logic to the server side was done, because it is easier to debug, tweak parameters and provides insights by enabling the real-time monitoring.

4 Results and Analysis

Android implementation was used together with the real-time monitoring to test congestion detection, in addition to collecting and analysing samples. In order to validate that the congestion detection algorithm is able to serve its purpose. The idea is to place it under controlled congestion where it is possible to turn on/off the congestion and see how the implementation reacts to it. However, it is hard for any individual to get a live network to the congestion level in a controlled manner, so the resort was in using network simulators.

4.1 Anritsu Mobile Network Simulator

The machine seen in Figure 25 only needed power and internet access and it was ready to operate. A SIM card was provided, then it was placed it in the Android mobile phone that is running the implementation for congestion detection. The machine can simulate RAN and CN, so the whole stack was there. The mobile phone was able to obtain packet access and the application was able to connect to own server. Everything was working in order, as the samples were collected and seen in the web interface.

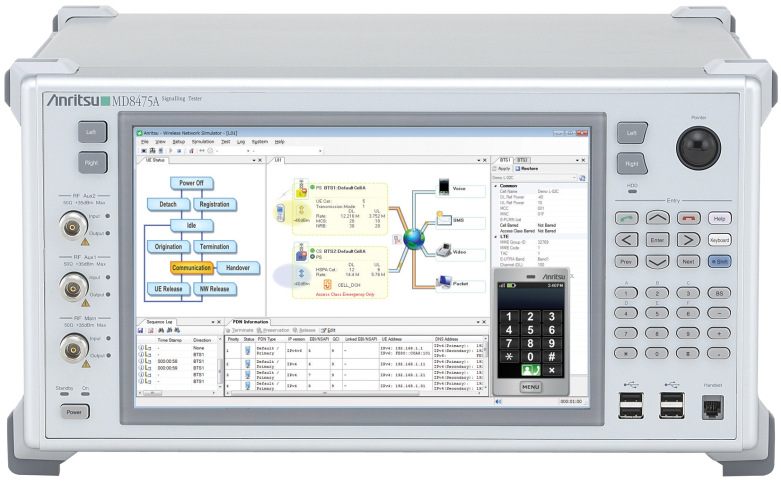


Figure 25. Signalling Tester (Base Station Simulator) MD8475A [18]

While it was relatively easy to get things working, the challenge was to simulate congestion. The first step was to find the process that takes the role of RNC and after that another process was ran with heavy load on the same CPU. An environment similar to real congestion was created while the heavy load fake process was competing on CPU resources. It is worth mentioning that starving the RNC process will simulate RNC level congestion, while congestion can be also on cell level, which is more difficult to reproduce. The congestion detection Android application is supposed to be able to detect RNC and cell level congestion.

At first, the application started to collect samples and study the network. The detection logic got activated after collecting twenty samples, it was enough to build a baseline of what is normal setup time for that hardware. After that, The starvation of RNC process was started by launching the heavy load fake process, and the good news is that in less than thirty seconds the Android application interface lighted up in red under congestion label, indicating that it was able to detect the congestion, on its own as seen in Figure 26.

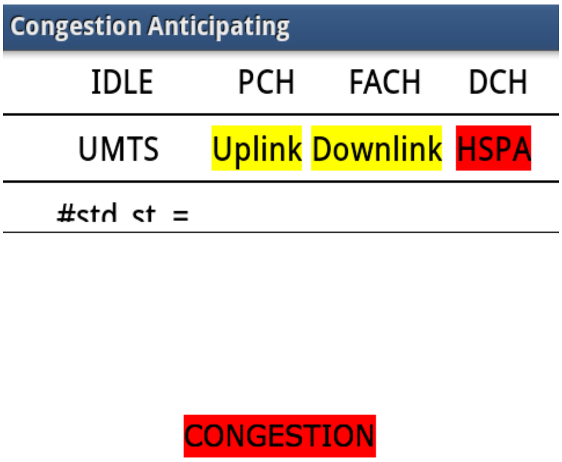


Figure 26. Android CRA implementation was able to detected congestion

Turning off the heavy load process and letting RNC process to function without CPU starvation, has reflected in the Android application. It changed the state and turned off congestion notification in less than twenty seconds. The experiment was repeated many times with consistent results; the Android application was able to detect the congestion period and the non-congestion period.

4.2 Finnish Operators (Elisa, Sonera, DNA)

Since the Android phone was running the congestion detection implementation, it was easy to run it against local mobile operators in Finland by simply placing a SIM card. The aim was not about detecting congestion but rather to collect samples and study QoE for their packet access.

In order to achieve similar environment for taking measurement, the same device was used, same time slot and same location. The location was a residential area in Espoo city, while the time slot was pick to be at afternoon on Saturdays, since it is expected that people will be at home and their mobile phones will be camping on same cells as the Android phone that is doing the measurements. Around 180 samples were collected within an hour and were stored in the database. The values of the samples (packet access establishment time) are plotted in the following chart (Figure 27).

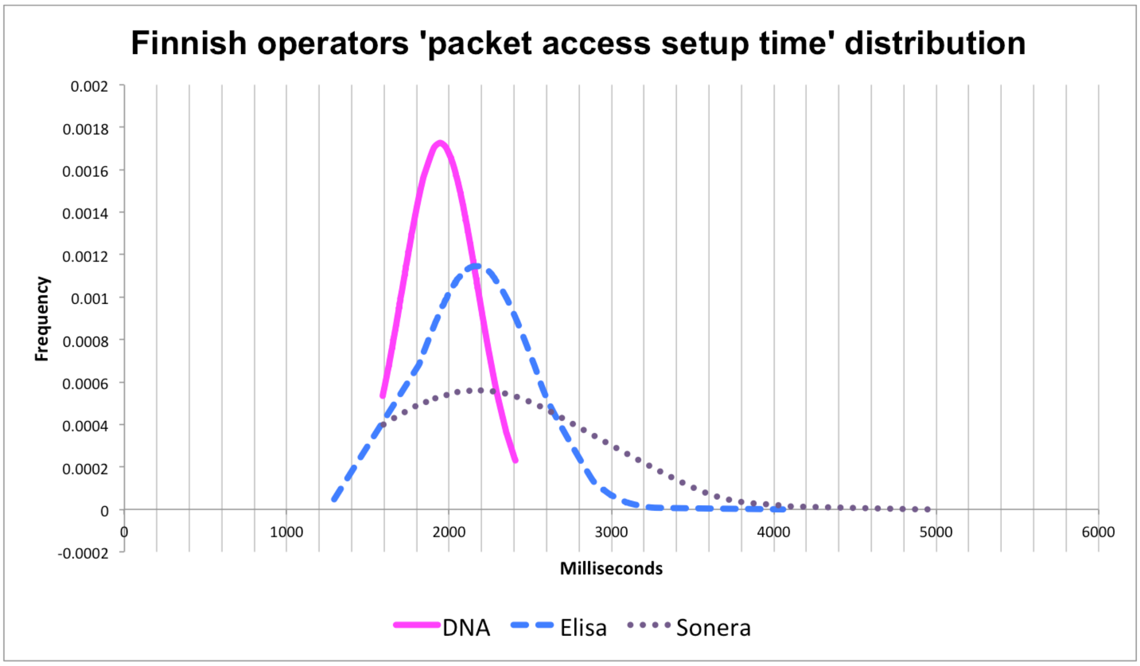


Figure 27. Samples of three Finnish operators

DNA seems to have the best results, as most of the values are around two seconds. On the other hand Elisa and Sonera seem to have more deviation from the mean. Different hardware setup that is used by different operators could explain a part of the results, in addition to the number of mobile devices being served. Congestion detection algorithm already overcomes those differences by allowing a learning period before it gets self activated. The learning period is simply taking samples and building an understanding of what is to be considered as normal values for this operator. Of course, the algorithm will update its learning gradually with time. In other words, one instance of congestion detection got used to the values of four seconds under Sonera network, then another might find the values alarming and worth firing a PCC (Potential Congestion Case) because it was used to two seconds values on DNA network.

Repeating the tests and measurements under same conditions for the three operators showed similar distribution curves, adding more reliability to results. However, there are many factors which can effect the results, and the results were taken under specific location, which means that the results does not reflect an overall image of an operator performance in serving packet access.

5 Conclusion and Recommendations

The number of mobile applications installed on smart phones is increasing rapidly, and the vast majority of them require internet connectivity. The infrastructure of mobile operators is built under the assumption that resources can be shared among subscribers, since it is less likely for every single subscriber's device to have the radio up at the same time. However, nowadays many mobile applications are indeed bringing the radio up more than expected and without direct request from the user. Typically, the reason is to check for new content or to send keep-alive messages to keep their connection with their content provider open. The benefit of keeping the connection open is that the server is able to push new content as soon as it arrives. The biggest offenders and users of this method are instant messaging applications.

All the players in the telecommunication domain have responded in different ways to the challenge. For example, network infrastructure manufacturers are calling for more hardware and more use of smaller cells to meet the demand, while smart phones operating systems trying to help and guide application developers towards more radio friendly network access.

This study joins those efforts by showing that it is possible to educate mobile devices about the condition of mobile packet access, which is greatly beneficial for end users, application developers and mobile operators alike. The algorithm is meant to be running independently on the mobile device and focuses mainly on measuring radio session setup time, which is the time it takes the radio to move from idle state to high state to transmit some data packets. Of course, not every abnormal value is a red alarm that is why most of the algorithm logic is about trying to eliminate false positives. Furthermore, there is a last stage filtering on the server side where all the reports from each instance are collected there. Those reports have information about quality of service, congestion situation and also explain why the logic concluded that there is congestion. The collective knowledge of the individually isolated and independent logic instance is very valuable when they are plotted on a map, so even if one of the logic instances in one of the mobile devices mistakenly trigged a final congestion decision that would be ignored, but if many instances agrees and reported congestion, then that can be taken seriously.

An Android implementation and a web application worked together to collect the reports and show the logic internals in real-time. They also were used to verify that the algorithm is able to detect congestion, in addition to a network simulator machine. Using the network simulator it was possible to have a controlled congestion environment by increasing CPU load on RNC process. The Android application was able to detect whenever there was increased load on the RNC. The implementation was also used against three operators in Finland. The results showed that CRA was able to adapt to different hardware and values.

The congestion recognition algorithm is generic and can be integrated at many levels of the radio stack of a mobile device. The candidates are baseband firmware, vendor native space or the operating system. The proposal here is to go even further and advertise the algorithm output for application developers as part of the development API offered by the operating system. Currently, the APIs that is offered by iOS and Android, which relates to mobile network, are very poor and limited. Application developers are trying all kind of tricks such as pinging some server to know if there is actually good connectivity. Broadcasting the algorithm output to mobile applications would make application developers' life easier and enable them to have better interaction with their users, e.g. as displaying the right message according to connectivity status.
There are a lot of use cases where independent real-time congestion detection can prove useful for the application vendors, network operator and end user. What follows are some ideas and examples to place the useful output of this study in the big picture that is the telecommunication field.

5.1 CRA for Mobile Network Operators

Many network measurement tools are available to network operators and they are monitoring it around the clock. However, they all present only one side of the story. CRA reports can provide the other side of the story, showing the packet call quality and establishment latency per cell-id, and that is on top of the congestion analysis and alerts.

Typically, a subscriber can be experiencing bad connectivity under specific areas and the operator has no idea what is happening until the subscriber calls customer service and reports the issue. Customer service can only check from a list of areas under maintenance and can easily deny the subscriber's claims since that location is not reported to be having problems according to the operator's measurements. If complains keeps coming and more subscribers are frustrated, the operator will send a diagnoses team in a special vehicle loaded with expensive equipment to measure the quality of experience. Now that can be partly avoided if the operator was getting a report containing the common knowledge of many CRA instances working independently and reporting their observation and decisions. This would serve as a great source of actual QoE that subscribers are experiencing.

5.2 CRA for Mobile Application Developers

Most of mobile application developers would like to know about current connectivity situation where they would apply different strategies. For example, a mobile TV application would drop down the stream quality even before it starts. Another example is for an application that offers small Internet packages to be bought by the subscriber, the application would be able to change some pricing on the fly. For example, offering a cheaper price if the user accepts that the internet will get activated after the congestion is gone.

Another example is for traffic optimization applications, where the congestion indicator provides obviously very useful input, as they can change the optimization level to be tighter or even block traffic completely when congestion is detected.

5.3 CRA for Mobile Operating Systems

Operating system has the best access to monitor and study the traffic. However, it is currently not taking full advantage of this privilege. Mobile OS can have congestion recognition algorithm to provide applications and the user a view over the quality of service and when there is congestion. This will help applications and users greatly, whereas applications can follow different techniques according to the latency being experienced by the user until a radio session is established. The same goes for the user where the operating system can show a notification to the user in case of increased latency and waiting time for establishing radio session.

Recently, mobile operating systems have put a lot focus on battery life measurements and calculations where it can show which application is consuming battery inefficiently. This study propose spending similar efforts to implement the algorithm explained in this study to show to users their QoE under different geographical locations with their respective operators. This allows users to compare between operators and pick the one which offers the best QoE in their preferred locations or overall. This can go a step further, if there was a collective data bases to show the result of all congestion recognition reports per operator per location, this will be an eye opener for the end users and mobile developers, where they can see real data from mobile devices like theirs and they don not have to trust operator advertisements. There is something similar for connection speed network latency, but the radio part of the equation is totally ignored.

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