Design And Implementation Of Multisite Cellular Network Based On Open Source System For Remote Areas

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Abstract: Blank spots are still a problem in some areas in Indonesia so that in some areas internet data services are not covered. One solution to overcome this problem is by building a transceiver system using an Open Source Mobile Communication (OSMOCOM). However, this system has relatively low power with a narrow coverage area, so a multisite scheme is needed to cover a wider area. Therefore, in this study, an open source cellular network based on OSMOCOM was developed and implemented that can deliver mobile network with data services and supports multisite schemes. We designed this system as a second and half generation (2.5) of cellular communication technology. From the test results of the realized system, the multisite network can work synchronously where the Mobile Station has received data services at all realized sites. Mobile Station can access the internet with an average throughput of 52.8 Kbps and guaranteed package loss of not more than 10%. Handover mechanism can work properly where it can move the Mobile Station from the original cell to the neighboring cell and vice versa based on the power received criteria. In the future, the proposed system is expected to be applied in remote areas or areas which is not covered by cellular services.

Index Terms: Base station, open source, GPRS, multisite, handover

1 INTRODUCTION

The factors that cause the unavailability of telecommunications networks in Indonesia, especially in remote areas, are very diverse, such as area contours, long distances and difficult to reach, so that telecommunications operators are reluctant to build networks in remote areas due to the high investment costs. Global System for Mobile Communications (GSM) - General Packet Radio Service (GPRS) can be used in areas where telecommunication networks are not yet available, because it has several advantages, including a wide signal range [1-4] although with a low transmit power [5-9], useful to be used to reduce the blank spot area [10-11]. To reduce the cost of building a Base Transmitter Station (BTS), several studies have been conducted [12], including those using SDR [13-14], such as OpenBTS for voice services [15-19] and Open source mobile communications (Osmocom) for GRPS services. [20], but there are still constraints on the limited coverage area [2, 20], so as to increase the coverage area, additional power is performed. The addition of power to a BTS transmitter requires a lot of power and can cause signal interference [21-24], so other methods are needed to increase coverage, one of which is to increase the number of BTS. Therefore, in this research, the development of previous research is carried out which has realized a standard GPRS-EDGE data communication system using Osmocom [20]. However, this system still uses one BTS so that the coverage and mobilization of Mobile Station is still limited. So that this system was developed using the concept of Multi-site BTS, where the system consists of several BTS that are in the same Base Station Controller (BSC), so that Mobile Station who receive services from Osmocom can still communicate with each other or can move places during be within the same BSC area or Intra-BSC handover. The proposed system is designed using low cost computers including Intel-NUC, USRP and Osmocom software. Intel NUC functions to store Osmocom applications and BTS-BSC configurations, while USRP functions as a transceiver (signal transmitter and receiver) for MS. The use of Osmo BTS and Osmo BSC technology as well as the appropriate handover algorithms, makes MS still get data services even though they move places. Osmo SGSN and Osmo GGSN are used as data service gateways between the operator signal and the proposed system.

2. NETWORK DESIGN AND IMPLEMENTATION

2.1 System Requirement

In designing the proposed system, a description of the device requirements and supporting tools were initially carried out. The GPRS multisite network in this study must be able to deliver data services and perform handover. This low-cost system also requires open source tools to run on a mini computer. We define this system requirement into two components including hardware and software. The list of components used in designing this multisite cellular system can be seen in Table 1. The GSM-GPRS network is designed with reference to the existing mobile network, including its components and functions. Sequentially from internet gateway, core network to baseband unit, they include Gateway GPRS Support Node (GGSN), Serving GPRS Support Node (SGSN), Mobile Switching Center (MSC), Home Location Register (HLR), Media Gateway (MGW), Base Station Controller (BSC), Packet Control Unit (PCU), and Base Transceiver Station (BTS) 1 - 2. This sub-system is built virtually based on open source software, namely OsmoBTS which is compatible to carry out mobile cellular communication without using a mobile network provider existing. OsmoBTS replaces GSM network operators that are equipped with GPRS applications so that they can communicate both voice and data. The GSM-GPRS network specifications built in this study are presented in Table 2.

TABLE 1. *LIST OF COMPONENTS*

Hardware required	Instal Software	Quantity
Intel NUC	Linux	2 unit
Mini PC	Osmo TRX	
	Osmo BTS	
	Osmo BSC	

	Osmo NITB Osmo PCU Osmo SGSN Osmo GGSN	
USRP	-	2 unit
Mobile Station	-	2 unit

All sub-systems are implemented and run on a mini personal computer (PC). We built this system on the intel NUC 8i5BEH series with the following specifications:

- Processor: Intel Core i5-8259U (2.3GHz up to 3.8GHz turbo, 6MB)
- Memory: DDR4 SO-DIMM 8GB
- Storage: SSD 240 GB
- Graphics: Intel IRIS Plus 655, 1x HDMI 2.0a, 1x Display Port 1.2 thunderbolt
- Network: GigabitLAN + WiFi AC-9560 + Bluetooth 5.0

GSM-GPRS architecture with a multisite scheme is presented in Figure 1. The mobile network implemented in this study has two active transmission cells (BTS-1 and BTS-2) connected to a BSC. Both BTS-1 and BTS-2 have overlapping coverage areas to ensure continuous service via the handover mechanism which is discussed further in the following sub-section.

2.2 Building The Core Network

The Core Network includes MSC, HLR, SGSN and GGSN which have the main function of building end-to-end connections, handover requests, user data logging and voice and internet service gateways. Figures 2 and 3 show the GGSN and SGSN configurations run on the PC server via the terminal (Command Console) when the network is on air. In GGSN, an Access Point Name (APN) is set with the name "internet" and the IP tunneling address given to the Mobile Station is 192.168.42.0/24. In this study configuration, the number of Mobile Station who can access is not limited by the system. From the SGSN console, there are users who have successfully connected to the GPRS network with the customer's IP address being 192.168.42.2. From SGSN, statistics can be seen from the data usage used by the user. The statistics displayed are in the form of incoming data and outgoing data in the form of bytes.

TABLE 2. *GSM-GPRS NETWORK SPECIFICATIONS WHICH ARE REALIZED IN THE PROPOSED SYSTEM*

Parameter	Value or configuration
IP GGSN	192.168.100.104
IP SGSN	192.168.100.250
IP UE	192.168.42.0/24
Hardware (server)	Mini PC intel NUC Prosesor i5 Ram 8GB
Hardware (Transceiver)	USRP B210 (SDR)
Antenna	Indoor GSM
Operating System	xUbuntu 18.04
MNC	1
MCC	1
Auth. policy	Accept-all
Internet	Support
Band	GSM900
ARFCN	50
Interface internet	Wifi
Interface GGSN	Wifi (wlp3s0)
Interface GGSN	Wifi (wlp3s0:0)
Encapsulation Protocol	UDP and TCP/IP
Number of cell	2
Handover (HO)	Support

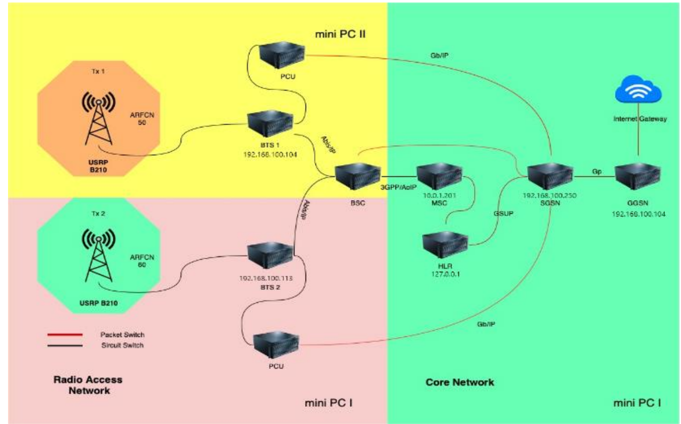
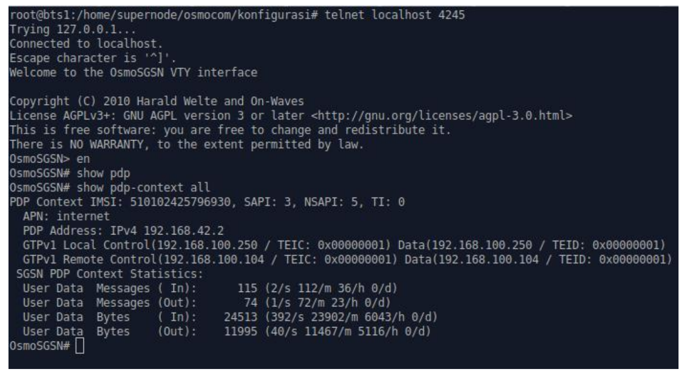


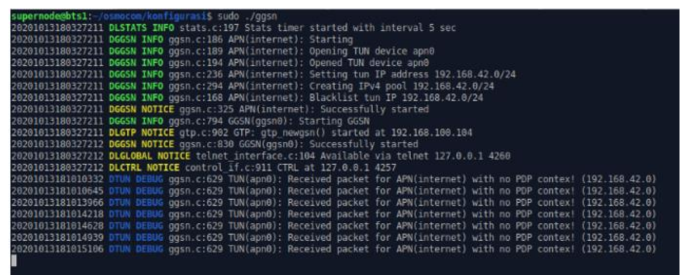
***Fig. 1**. Proposed multi-site GPRS network architecture*



```
root@bts1:/home/supernode/osmocom/konfigurasi# telnet localhost 4245
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
Welcome to the OsmoSGSN VTY interface

Copyright (C) 2010 Harald Welte and On-Waves
License AGPLv3+: GNU AGPL version 3 or later <http://gnu.org/licenses/agpl-3.0.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
OsmoSGSN> en
OsmoSGSN# show pdp
OsmoSGSN# show pdp-context all
PDP Context IMSI: 510102425796930, SAPI: 3, NSAPI: 5, TI: 0
  APN: internet
  PDP Address: IPv4 192.168.42.2
  GTPv1 Local Control(192.168.100.250 / TEIC: 0x00000001) Data(192.168.100.250 / TEID: 0x00000001)
  GTPv1 Remote Control(192.168.100.104 / TEIC: 0x00000001) Data(192.168.100.104 / TEID: 0x00000001)
 SGSN PDP Context Statistics:
  User Data  Messages ( In):       115 (2/s 112/m 36/h 0/d)
  User Data  Messages (Out):        74 (1/s 72/m 23/h 0/d)
  User Data  Bytes    ( In):     24513 (392/s 23902/m 6043/h 0/d)
  User Data  Bytes    (Out):     11995 (40/s 11467/m 5116/h 0/d)
OsmoSGSN#
```

***Fig. 2**. GGSN console*



```
supernode@bts1:~/osmocom/konfigurasi$ sudo ./ggsn
20201013180327211 DLSTATS INFO stats.c:197 Stats timer started with interval 5 sec
20201013180327211 DGGSN INFO ggsn.c:186 APN(internet): Starting
20201013180327211 DGGSN INFO ggsn.c:189 APN(internet): Opening TUN device apn0
20201013180327211 DGGSN INFO ggsn.c:194 APN(internet): Opened TUN device apn0
20201013180327211 DGGSN INFO ggsn.c:236 APN(internet): Setting tun IP address 192.168.42.0/24
20201013180327211 DGGSN INFO ggsn.c:294 APN(internet): Creating IPv4 pool 192.168.42.0/24
20201013180327211 DGGSN INFO ggsn.c:168 APN(internet): Blacklist tun IP 192.168.42.0/24
20201013180327211 DGGSN NOTICE ggsn.c:325 APN(internet): Successfully started
20201013180327211 DGGSN INFO ggsn.c:794 GGSN(ggsn0): Starting GGSN
20201013180327211 DLGTP NOTICE gtp.c:902 GTP: gtp_newgsn() started at 192.168.100.104
20201013180327212 DGGSN NOTICE ggsn.c:830 GGSN(ggsn0): Successfully started
20201013180327212 DLGLOBAL NOTICE telnet_interface.c:104 Available via telnet 127.0.0.1 4260
20201013180327212 DLCTRL NOTICE control_if.c:911 CTRL at 127.0.0.1 4257
20201013181010332 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
20201013181010645 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
20201013181013966 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
20201013181014218 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
20201013181014628 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
20201013181014939 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
20201013181015106 DTUN DEBUG ggsn.c:629 TUN(apn0): Received packet for APN(internet) with no PDP contex! (192.168.42.0)
```

***Fig. 3**. SGSN console*

2.3 Building The Radio Access Network

The main components in the Radio Access Network (RAN) include BSC and BTS. The regulation in BSC is Timeslot allocation to allocate channels, where in this system, GPRS service allocations are in timeslots 4 and 5. Channel control is allocated to timeslots 1 and 2. Meanwhile, other timeslots are used for voice channels. The details of the timeslot allocation are presented in Table 3.

TABLE 3. *TIMESLOT ALLOCATION*

Timeslot	Channel Function
Timeslot 0	CCCH+SDCCH4 (control)
Timeslot 1	SDCCH8 (control)
Timeslot 2	PDCH
Timeslot 3	PDCH
Timeslot 4	PDCH (data)
Timeslot 5	PDCH (data)
Timeslot 6	PDCH
Timeslot 7	PDCH

The configuration of BTS-1 and BTS-2 when conditions are on air is shown in Figures 4. This BTS-1 has an identity (cell ID) 1111, ARFCN = 50 and a neighboring cell that can be connected automatically as many as two cells with ARFCN 60 and 70. Mobile Station who can connect must meet the minimum capture power of -110 dBm, as shown in Figure 4. Meanwhile the identity of BTS-2 is 2222 with ARFCN = 70, neighboring cells that can access have ARFCN 50 and 60, as shown in Figure 5. This configuration is then defined in the USRP B210 hardware to perform radio transmission functions and physical connection with the Mobile Station. The implemented GPRS mobile network provides services at a frequency of 900 MHz with a maximum transmit power of 23 dBm which is transmitted using an omnidirectional antenna.

```
BTS 0 is of sysmobts type in band GSM900, has CI 1111 LAC 1111, BSIC 11 (NCC=1, BCC=3) and 1 TRX
  Description: "B210"
  ARFCNs: 50
  PCU version 0.8.0 connected
  MS Max power: 0 dBm
  Minimum Rx Level for Access: -110 dBm
  Cell Reselection Hysteresis: 4 dBm
  Access Control Class ramping: not enabled
  RACH TX-Integer: 9
  RACH Max transmissions: 7
  Uplink DTX: not enabled
  Downlink DTX: not enabled
  Channel Description Attachment: yes
  Channel Description BS-PA-MFRMS: 5
  Channel Description BS-AG_BLKS-RES: 1
  System Information present: 0x0000087e, static: 0x00000000
  Early Classmark Sending: 2G forbidden, 3G allowed (forbidden by 2G bit)
  Unit ID: 1111/0/0, OML Stream ID 0xff
  NM State: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  Site Mgr NM State: Oper 'Enabled', Admin 'Locked', Avail 'OK'
  GPRS NSE: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  GPRS CELL: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  GPRS NSVC0: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  GPRS NSVC1: Oper 'Disabled', Admin 'Locked', Avail 'Off line'
  Paging: 0 pending requests, 50 free slots
  OML Link: (r=127.0.0.1:34219<->l=127.0.0.1:3002)
  OML Link state: connected 0 days 0 hours 5 min. 6 sec.
  Neighbor Cells: Automatic, ARFCNs: 60 70 (2)
  Current Channel Load:
            CCCH+SDCCH4:   0% (0/4)
                 SDCCH8:   0% (0/8)
  CBCH BASIC: 0 messages, 0 pages, 0-entry sched_arr, 0% load
  CBCH EXTENDED: 0 messages, 0 pages, 0-entry sched_arr, 0% load
  Channel Requests        : 0 total, 0 no channel
  Channel Failures        : 0 rf_failures, 0 rll failures
  BTS failures            : 1 OML, 1 RSL
  base transceiver station:
   Channel load average.:        0 %
   T3122 IMMEDIATE ASSIGNMENT REJECT wait indicator.:       10 s
   RACH slots with signal above threshold:       0 %
   RACH slots with access bursts in them:       0 %
```

Fig. 4. *The configuration of BTS-1*

```
BTS 1 is of sysmobts type in band GSM900, has CI 2222 LAC 2222, BSIC 22 (NCC=2, BCC=6) and 1 TRX
  Description: "N210"
  ARFCNs: 70
  PCU version 0.8.0 connected
  MS Max power: 0 dBm
  Minimum Rx Level for Access: -110 dBm
  Cell Reselection Hysteresis: 4 dBm
  Access Control Class ramping: not enabled
  RACH TX-Integer: 9
  RACH Max transmissions: 7
  Uplink DTX: not enabled
  Downlink DTX: not enabled
  Channel Description Attachment: yes
  Channel Description BS-PA-MFRMS: 5
  Channel Description BS-AG_BLKS-RES: 1
  System Information present: 0x0000087e, static: 0x00000000
  Early Classmark Sending: 2G forbidden, 3G allowed (forbidden by 2G bit)
  Unit ID: 2222/0/0, OML Stream ID 0xff
  NM State: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  Site Mgr NM State: Oper 'Enabled', Admin 'Locked', Avail 'OK'
  GPRS NSE: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  GPRS CELL: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  GPRS NSVC0: Oper 'Enabled', Admin 'Unlocked', Avail 'OK'
  GPRS NSVC1: Oper 'Disabled', Admin 'Locked', Avail 'Off line'
  Paging: 0 pending requests, 50 free slots
  OML Link: (r=192.168.100.113:40397<->l=192.168.100.104:3002)
  OML Link state: connected 0 days 0 hours 0 min. 28 sec.
  Neighbor Cells: Automatic, ARFCNs: 50 60 (2)
  Current Channel Load:
            CCCH+SDCCH4:   0% (0/4)
                  TCH/F:   0% (0/4)
                 SDCCH8:   0% (0/8)
  CBCH BASIC: 0 messages, 0 pages, 0-entry sched_arr, 0% load
  CBCH EXTENDED: 0 messages, 0 pages, 0-entry sched_arr, 0% load
  Channel Requests        : 0 total, 0 no channel
  Channel Failures        : 0 rf_failures, 0 rll failures
  BTS failures            : 0 OML, 0 RSL
  base transceiver station:
   Channel load average.:        0 %
   T3122 IMMEDIATE ASSIGNMENT REJECT wait indicator.:       10 s
   RACH slots with signal above threshold:       0 %
   RACH slots with access bursts in them:       0 %
```

Fig. 5. *The configuration of BTS-2*

2.4 Handover Mechanism

Handover (HO) is an important feature in a multisite communication system to ensure service to users when moving places. With service handover still provided to active users when moving from one site to another. The implemented system has two sites which are covered by BTS-1 and BTS-2 where the coverage areas intersect. When the Mobile Station moves from the coverage area of BTS-1 to BTS-2 and the service transfer criteria have been met, the Mobile Station will be served by BTS-2 without any interruption of service. In this system, the handover applied is intra or internal BSC, which means that the handover occurs between BTS within the same BSC network so that the handover algorithm is executed on the BSC. In general, the handover mechanism that is applied is based on the signal strength received by the Mobile Station as illustrated in Figure 6. The Mobile Station will measure 10 times and then calculate the average received power of the two BTS, the receiving power is then compared. Mobile Station will get services by BTS with greater receiving power. Figure 7 shows the complete configuration of the handover mechanism implemented on BSC.

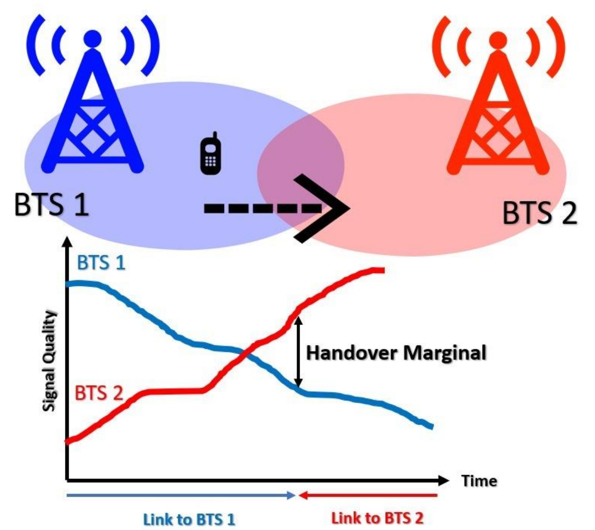


Fig. 6. *The Handover mechanism based on power signal quality*

```
handover 1
handover window rxlev averaging 10
handover window rxqual averaging 1
handover window rxlev neighbor averaging 10
handover power budget interval 6
handover power budget hysteresis 3
handover maximum distance 9999
timer t3101 10
timer t3109 4
timer t3113 60
timer t3122 10
```

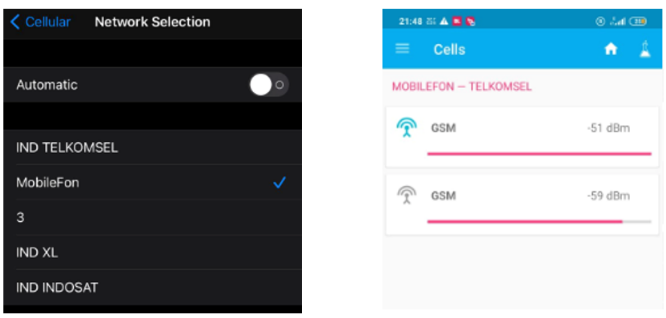
Fig. *7. The configuration of BSC*

3. RESULTS AND DISCUSSION

After designing the network, configuring the virtual components and applying the handover algorithm on this GPRS system, then the performance tests are carried out for both functionality and quality of service. The performance test includes a service availability and connection test, a GPRS service test, quality of service and handover test. The following sub-section contains a detailed explanation of the test results followed by a discussion for each scenario.

3.1 Service Availability and Connection Physical Test

The mobile wireless network which was developed is designed to provide internet services based on 2.5 Generation technology. Mobile Station with at least 2G technology can connect to this network. This mobile network is designed to be open access, which means there is no registration or special requirements to be connected. We named this network "MobileFon". To connect with this network, data roaming and 2G services must be activated on the mobile phone. In this scenario, we activated the connection on five mobile phones then performed a manual network search as shown in Figure 8(a). The “MobileFon” network is available and Mobile Station can establish a connection as shown in Figure 8 (b). The subscriber number (MSISDN) for all mobile phone has been registered on the HLR. In this condition, users can make phone calls and send messages to each other.



(a) (b)

Fig. 8. *(a) search for the MobileFon network (b) establishing a connection with the MobileFon network*

The next test scenario is to connect the Mobile Station to internet services, which is one of the main issues in this study. Users can activate internet services by turning on data services on the user interface. If the internet connection has been established, the screen will display the symbol "G" or "E" which means GPRS-EDGE, and the Mobile Station will get an IP address. Figure 9 below shows a Mobile Station which has connected with an internet service. The service coverage area is also a concern that is tested on this system. This test aims to determine the maximum coverage where the network still provides services. The test is carried out in an open area where the BTS and Mobile Station are in line of sight (LOS) conditions. From the test results shown in Table 4, it is found that the maximum radius is 90 meters with a received signal strength of -105 dBm. Referring to the GSM standard by ITU-T, the received signal strength can still be served with “poor” quality.

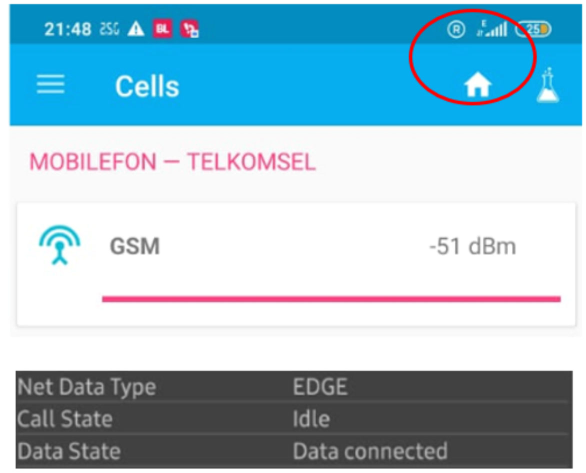


Fig. 9. *(a) search for the MobileFon network (b) establishing a connection with the MobileFon network*

TABLE 4. *COVERAGE TEST RESULTS*

Distance	Received signal strength (dBm)	Status
5	-51	Connected (Excellent)
10	-56	Connected (Excellent)
20	-64	Connected (Excellent)
30	-70	Connected (Excellent)
40	-75	Connected (Good)
50	-81	Connected (Good)
60	-87	Connected (Good)
70	-93	Connected (Good)
80	-98	Connected (Good)
90	-105	Connected (poor)
100	-111	Not connected
110	-119	Not connected
120	-125	Not connected

3.2 Quality of Service (QoS)

QoS measurements include throughput, delay, and packet loss with the scenario of a Mobile Station connected in excellent quality conditions. This is intended to get the best performance. The measurements were performed using Wireshark when the Mobile Station accessed www.detik.com. The measurements were carried out 30 times (captured every 10 seconds) with a total duration of five minutes. The QoS test results are presented in Table 5.

TABLE 5. *MEASUREMENT RESULTS OF QOS*

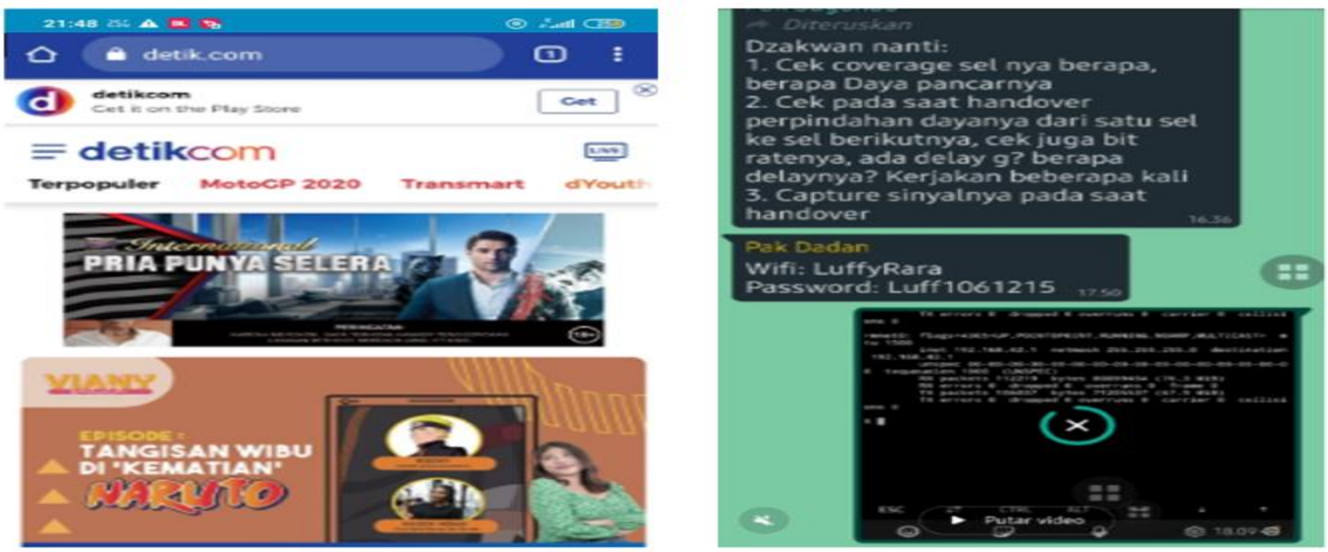
No	Throughput (kbps)	Delay (s)	Packet Loss (%)
1	55	0.043	6.6
2	81	0.046	0.9
3	56	0.051	0
4	67	0.045	11.8
5	43	0.047	5.2
6	90	0.042	0
7	9.4	0.196	0
8	93	0.081	0
9	7.8	0.158	15
10	80	0.052	4.7
11	12	0.086	9.9
12	58	0.052	29.6
13	56	0.052	3.6
14	100	0.037	0
15	60	0.057	0

16	84	0.056	0
17	45	0.121	0
18	58	0.091	21.8
19	31	0.042	33.9
20	70	0.046	9.5
21	70	0.035	11.6
22	24	0.039	9.7
23	30	0.053	13.7
24	40	0.045	6.1
25	74	0.044	0.9
26	106	0.035	0.4
27	40	0.041	1.3
28	13	0.043	0
29	13	0.155	0
30	18	0.210	0
Ave.	52.8	0.070	6.54

From Table 5, it is shown that the average throughput generated is 52.8 kbps which is lower than the 3GPP recommendation where theoretically, the throughput on the GPRS network is 171 kbps. The maximum throughput that can be achieved is 106 kbps so that the average throughput reaches half of the calculated maximum throughput value. The system performance in this case is that the throughput is not in appropriate with the theory because the Mobile Station does not get the full data timeslot allocation so that the downlink throughput decreases.

Meanwhile, the average packet loss generated was 6.54%. According to ITU-T G.114 [25], packet loss <10% is still in the "acceptable" category for GPRS. Packet loss can be caused by the large number of data queues on the network, causing congestion. As we know, the developed system consists of many components which run on a mini computer, the packet can be dropped when the data transmission speed between segments is out of sync. However, the TCP protocol will ensure the packet reaches its destination with a re-transmission procedure with the consequence of additional time or latency for data re-transmission.

Figure 10 (a) and 10 (b) below is the result of browsing and receiving-sending data on a mobile phone.



(a) (b)

***Fig. 10**. (a) browsing (b) chat on Whatsapp*

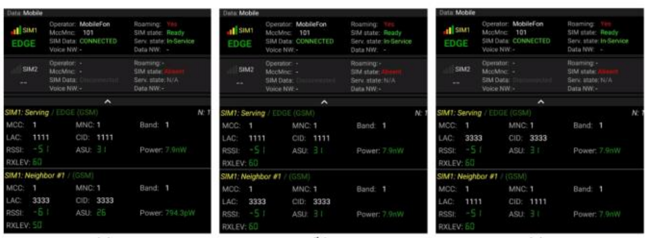
***TABLE 6.** THE HANDOVER TEST RESULTS*

No	Serving cell ID, RSSI (dBm)	Neighbor Cell ID, RSSI (dBm)	RSSI Neighbor when ME approaches (dBm)	Handover
1	1111, -51	3333, -61	-51	Success
2	1111, -53	3333, -57	-53	Success
3	1111, -87	3333, -93	-87	Success
4	1111, -63	3333, -71	-63	Success
5	1111, -53	3333, -61	-53	Success
6	3333, -51	1111, -57	-51	Success
7	3333, -53	1111, -61	-53	Success
8	3333, -53	1111, -63	-53	Success
9	3333, -63	1111, -69	-63	Success

10	3333, -53	1111, -60	-53	Success

3.3 Handover Test

One of the important features of a multisite network is that it supports a handover mechanism. This is to ensure that the service will still be provided to the user even though they have moved service areas. We designed the HO mechanism on this network based on the signal received level comparison. If the signal level of neighboring cells is greater than that of serving cells, HO is recommended. The HO test scenario is by moving the Mobile Station from the original cell to the neighboring cell and vice versa as shown in Figure 6. The handover test results are presented in Table 6. From the tests carried out 10 times, the implemented HO algorithm has succeeded in transferring services from one cell to another and vice versa. When the Mobile Station approaches the neighboring cell's service area, the RSSI will increase followed by a decrease in the RSSI of the serving cell then HO occurs if the RSSI of the neighbouring cell is greater than the RSSI of the serving cell. The HO stages are shown in Figure 11 using the "network cell info" application.



(a) (b) (c)

***Fig. 11**. Handover stages (a) initial serving cell, (b) Mobile Station approaching neighbour cell, (c) HO has succeeded.*

4. CONCLUSION

This study was successful in designing and implementing a multisite cellular network based on an open source system. The Osmocom Multisite system that provides internet services based on 2.5 Generation technology can function properly, the Mobile Station still gets data services even when moving places, and the handover work properly where the Mobile Station move from the original cell to the neighbouring cell based on the power received criteria. Maximum service coverage is 90 meters with a received signal strength of -105 dBm. The average throughput generated is 52.8 kbps, the maximum throughput that can be achieved is 106 kbps so that the average throughput reaches half of the calculated maximum throughput according to ITU-T G.114. The proposed system is expected to be used in remote areas or blank spots when considering resource efficiency and low cost in installation.

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