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Improving the performance of wireless network in residential areas in Kuwait

Ali F. Almutairi*, Yousef Al-Bader and Mishal Al-Gharabally

Electrical Engineering Department, Kuwait University
**Corresponding Author: ali.almut@ku.edu.kw*

ABSTRACT

Data usage on mobile networks has been increasing exponentially in the State of Kuwait, where current 4G network speeds no longer meet the demands of the average users. This created the need to improve the system performance to increase the downlink data rate. In this paper, current 4G network performance and limitations are presented, and a wireless system, which uses the concepts of cell densification, Multiple-Input Multiple-Output (MIMO) antenna, beam forming, and Point-to-Multipoint (PTM) communication, is proposed to improve the data rate in residential areas in Kuwait. The proposed system is simulated, and the performances of the existing network and the proposed system are compared in terms of the user downlink data rate. The introduction of the concepts of cell densification, MIMO, beam forming, and PTM has increased the data rate substantially. The performance of the wireless network of a typical town in Kuwait called Qortuba has been investigated. Based on the data collected, the average user data rate is 5.33 Mbps in the existing network. With the proposed system, if the number of cells is kept the same (12 cells), the data rate will increase to 20.4 Mbps. If the number of cells increases (43 Cells) to explore the full potential of the proposed system, the average user data rate will increase from 19.01 Mbps to 73.36 Mbps.

Keywords: Beam forming; cell densification; MIMO; PTM; residential area; wireless network.

INTRODUCTION

In the era of technological advancements, IT applications have become an inseparable part of every person's life. They come in many forms, whether accessing their social media accounts or streaming videos from websites. In 2017, 80-90% of IP traffic was from video communication; this corresponds to almost 41 million DVDs per hour (CISCO.com, 2016). In order to enjoy these services and upcoming new ones, high data rates and low latency are required. In November 2012, the first 4G network (Govil, 2007) was launched in Kuwait, where users got an average data rate of 8-30 Mbps and an average latency of 24 ms (ZAIN.com, 2012). The faster connection was achieved by increasing the channel bandwidth to 20 MHz and using the Orthogonal Frequency Division Multiple Access (OFDMA) technique (Navita, 2016). At the same time, advanced Multi-Input Multi-Output (MIMO) techniques were used to create spatially separated paths (Padmaja, 2014). Finally, carrier aggregation enabled user devices to aggregate up to 100 MHz of bandwidth to get the high data rates (Yi, Chun, Lee, Park, & Jung, 2013).

The speeds achieved with the 4G network made residents of Kuwait rely mainly on their mobile networks as their main gateway to the internet instead of the conventional Internet Service Provider (ISP). This is mainly caused by the lack of fiber infrastructure in many residential areas. ISPs provided speeds ranging from 256 Kbps to 8 Mbps, which is barely the speed of 4G. Another factor causing the dependency on mobile networks is the price. Getting a 4G connections costs about 33$ monthly, while to get a speed of 8 Mbps with an ISP would cost 330$+ monthly, depending on which ISP. In December 2016, prices of ISP's were forcibly lowered by the Ministry of Communication by over 40%, but even with these prices, the users got used to connecting through the mobile networks (ALRAI, 2016).

User dependency on cellular data created a huge load on Mobile Network Operators (MNOs) in Kuwait. Currently there are 3 MNOs offering cellular services in Kuwait. Mobile user data usage in Kuwait, for one of the MNOs, is measured and shown in Figure 1. As shown in that figure, the data usage in Kuwait has been increasing exponentially. This behavior is not unique to Kuwait. According to the Cisco visual network index (VNI) 2016 (CISCO, 2017), a worldwide compound annual growth rate (CAGR) of 47% in mobile data usage will be seen by 2021, as shown in Table 1, where Exabytes (EB) is equal to 10^9 Gigabytes (GB). It is worth mentioning that the Middle East and North Africa (MENA) Region will be seeing a 96% increase in mobile data usage per year (CISCO, 2017). This is the highest increase in any region in the world. Such increase can be attributed to the lack of wired communication networks infrastructure in many countries in the MENA region.

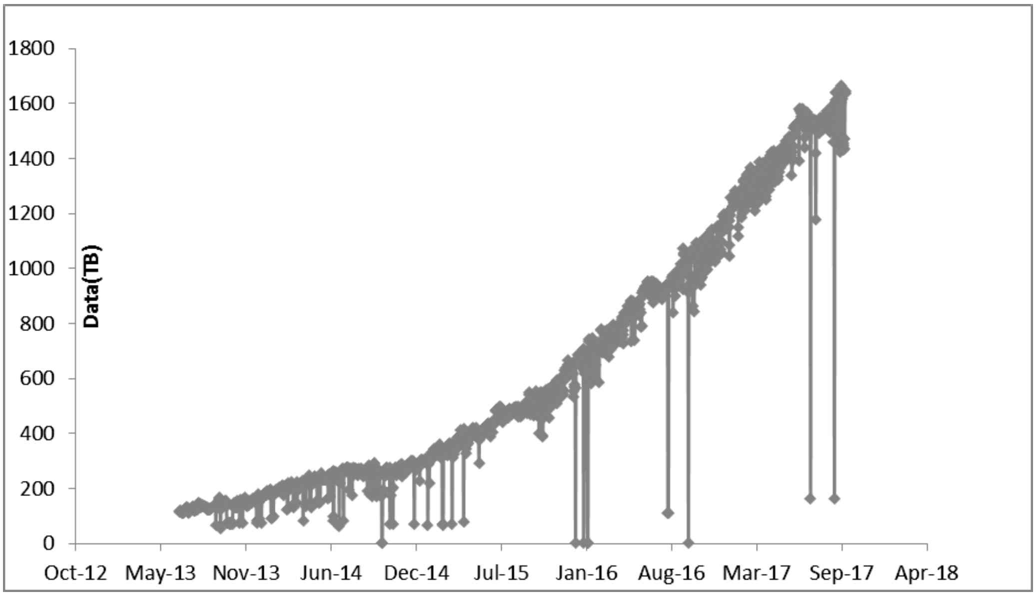

Figure 1. Actual data usage in Kuwait by one of the MNO.

Due to the late introduction of costly 4G networks, many service providers will not be motivated to introduce new costly systems soon. In 5G systems (Shafi 2017, Agyapong 2014), it is expected that new services will require more than 100 times the current bandwidth speed. In addition, as we are entering the age of the Internet of Things (IoT), the network will have to be ready to host 1,000 times the number of current devices. These requirements cost considerable amounts of money that MNOs will have to pay in order to expand their networks. Furthermore, due to the late introduction of 4G networks, and types of industries and economies of the MENA region, 5G networks will not be introduced in the feasible future. Therefore, the MENA region should focus its efforts on improving its existing wireless networks' performance. This sparked the need to come up with a solution that is low in cost and guarantees quality of service (QoS) in terms of downlink data rates. The proposed system will help MNO's in MENA region to better utilize their existing networks.

Table 1. Worldwide data usage (CISCO, 2017).

Year	Data Usage (EB)
2016	7
2017	11
2018	17
2019	24
2020	35
2021	49

PROPOSED SYSTEM-ENABLING TECHNOLOGIES

There are four major enabling technologies of the proposed network: cell densification (Bright, 2014; Bennis, 2013; Gelabert, 2013), MIMO (J.Lee, 2009; Mucalo, 2013; Navita, 2016), beam forming (Lott, 2006; Chaipanya, 2014), and Point-to-Multipoint communication (PTM) (Znati, 2002; Gomez-Barquero, 2018; Awada, 2016; Wu, 2018). These technologies will be discussed in some detail in this section.

Small cells (cell densification) are low-power wireless access points that operate in licensed and unlicensed spectrums. The cells may or may not be managed by the operator. The main purpose of small cells or cell densification is to cover the relatively short range of the higher frequencies that provide the high speeds. There are many types of small cells, such as Femto, Pico, Micro, Metro, and Wi-Fi (Bright, 2014; Bennis, 2013; Gelabert, 2013). These types are different in the number of users they can support, environments where they can be used, their indoor power range, and their coverage range. By comparing the range of coverage for different cell types, we can eliminate the Metro and Micro cells from being used in cell densification in residential areas of Kuwait due to them having a coverage range of hundreds of meters, which is beyond the boundaries of residential homes. Since the support for a large number of users is not required for cell densification for residential homes, the Pico cell can be eliminated. The remaining cell types are the Wi-Fi cell and the Femtocell, which can be the main candidates for the proposed cell densification in the residential areas in Kuwait.

MIMO (J.Lee, 2009; Mucalo, 2013; Navita, 2016) is the ability to use two or more transmitters and receivers to send and receive data at the same time to reduce the Bit Error Rate (BER) and increase the data rate. In today's 4G base stations, about a dozen ports for antennas are available that handle the cellular traffic. Eight of the antennas are transmitters and four are receivers. This 4G setup can only reach a maximum of 4X4 MIMO. This corresponds to end users connecting to four antennas at the same time, where their bandwidth will be aggregated.

In beam forming, the signal is steered in a particular direction towards a user by changing the phase and amplitude of signals applied to individual elements of the antenna array (Lott, 2006; Chaipanya, 2014). Therefore, beam forming techniques improve the performance of a wireless system by directing the beam toward the desired user and at the same time reducing the interference to the other users. This will result in better performance in terms of BER and increase the data rate of the desired user.

The concept of Point-to-Multipoint communication (PTM) (Znati, 2002; Gomez-Barquero, 2018; Awada, 2016; Wu, 2018) is applied in the proposed system. PTM uses beam forming and MIMO technologies to guide a signal to a specific receiver. Given the advantage of MIMO, each transmitter antenna would be able to cater to multiple receiver antennas as if it was Point-to-Point communication. Through the use of PTM, a semi-dedicated channel will be allocated for subscribers, which will help ensure that fixed bandwidth can be achieved at the receiver side.

CURRENT PERFORMANCE OF WIRELESS NETWORK IN RESIDENTIAL AREA

Many factors impact 4G network performance in residential areas of Kuwait. The first factor is the lack of fiber infrastructure. The second is the dense population in small areas. Another factor is the lack of base stations in some areas.

For a case study of the proposed system, we have considered a typical residential area in Kuwait called Qortuba. The urban plan of the town of Qortuba is shown in Figure 2. Qortuba has a surface area of about 3.06 km^2, which contains about 1,970 houses. Currently, Qortuba has 12 base stations to provide cellular services. With the assistant of one of MNOs in Kuwait, it was possible to collect the data for the year 2017 as shown in Table 2.

Figure 2. Typical Kuwaiti residential town, Qortuba.

It can be observed from Table 2 that the maximum number of 4G users can be calculated by summing the maximum number of users per base station, which gives a total of 6681 users. The average number of users in Qortuba town is 4,625 users. The average downlink throughput that a subscriber gets is 5.33 Mbps.

Table 2. Measured data throughput in Qortuba for the year 2017.

Site #	Sum of bandwidth (MHz)	Average number of users	Max number of users	User Downlink Average Throughput (Mbps)
909	135	368	549	2.2895
1231	75	214	307	3.9718
1471	165	522	724	4.7001
1625	210	545	789	5.3219
1635	165	333	532	7.2324
1653	165	593	837	3.8149
1634	165	516	717	5.2146
1616	220	488	689	6.0039
4144	135	210	353	4.6195
1680	135	328	444	6.127
1660	180	276	397	7.3852
1652	135	232	343	7.3604

In Figure 3, even though the area has excellent coverage, the speeds are nowhere near the 4G assumed speeds. As an example, the area of site number 1,653 shown in Figure 3 has excellent coverage, but the actual average user throughput is 3.8149 Mbps (Table 2). This is a clear indication that coverage is not the issue; rather, the actual downlink data rate that users receive is the problem.

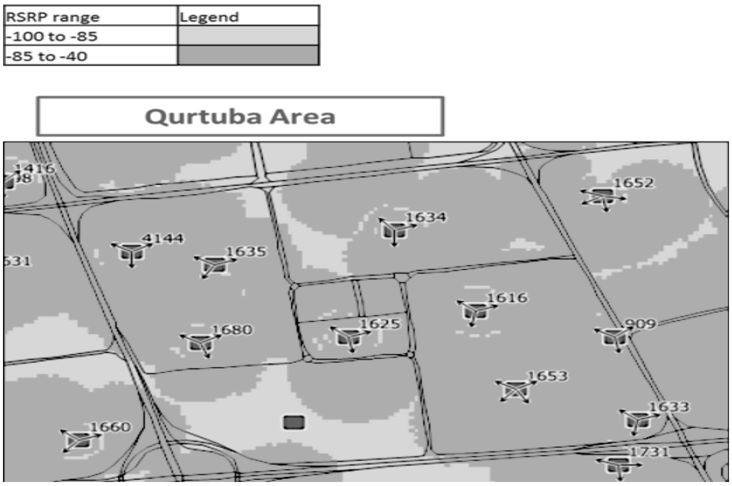

Figure 3. A typical coverage of the town of Qortuba.

PROPOSED WIRELESS NETWORK SYSTEM FOR RESIDENTIAL AREA

Considering all the above factors, the following technical solution, shown in Figure 4, is suggested. In the proposed concept, each base station (Number 1 in Figure 4) will have MIMO antennas that will beam form the signal to a small fixed directional receiver antenna on top of each house (Number 2 in Figure 4). The directional antenna is then connected to an amplifier (Number 3 in Figure 4) that is connected to an 802.11ac Wi-Fi cell (Number 4 in Figure 4) that has EAP-SIM capabilities, which will allow users to be authenticated by the mobile network operator and be provided with their services.

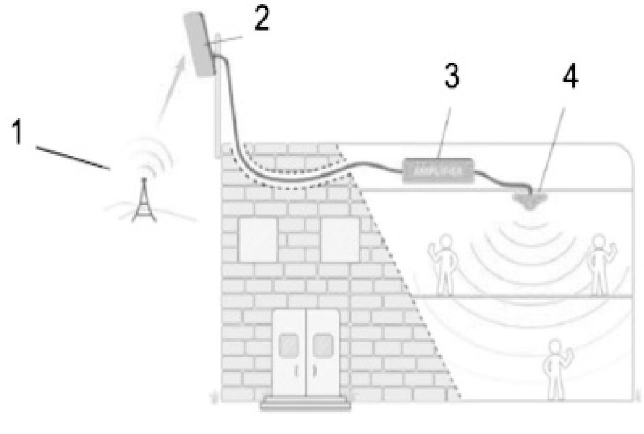

Figure 4. Proposed wireless network.

This approach provides end users with fixed bandwidth and higher data rates. It will also allow MNOs to monitor the usage of their subscribers as if they were on their cellular network. MNOs will also not need to worry about coverage indoors as home owners can install their own Wi-Fi repeaters. Another benefit of this approach is the low cost on the end user side where the small antenna costs approximately between 300-500$ and is a one-time installation. Also, users do not need to change their devices since the proposed approach works on Wi-Fi standards.

PERFORMANCE ANALYSIS

The Public Authority of Housing (PAH) in Kuwait specifies only one fixed base station site per 0.64 Km^2 (PAHW, 2018). Currently, Qortuba has 12 base stations. Taking this into consideration, we need to use low number of base stations possible. Comparing the candidate MIMO+ Beam Forming antennas presented in (Kim, 2014; Nam, 2013; S. Rajagopal, 2011; J. Hoydis, 2013), the "MIMO+ 3D–BF" antenna provides speeds up to 5125 $Gb/s/Km^2$ but has a drawback of requiring 115 cells to cover 1 Km^2. Such a requirement is impractical in residential areas in Kuwait. On the other hand, the "Full Dimension (FDD) MIMO +3D-BF" provides a suitable 9 $Gb/s/km^2$ while only requiring 14 cells to cover 1 Km^2. The "Adaptive Antenna Array (TR) BF" and the "Massive MIMO" candidates do not support enough users per cell. The most suitable candidate for the proposed system, which balances between the number of base stations and the number of users, is the "Full Dimension (FDD) MIMO +3D-BF" where, in order to cover the area of Qortuba, a total of 43 (14 cells/Km^2*3.06Km^2) base stations are needed to explore the full potential and capabilities of the proposed system. Furthermore, according to a comparison of different small cell technologies (Bright, 2014; Bennis, 2013; Gelabert, 2013), the only small cell technology that can deliver Gbps speed is 802.11ac Wi-Fi. With the EAP-SIM authentication protocol, the mobile user will be able to get access to the required speed with by using any 802.11ac Wi-Fi capable device.

According to 3GPP LTE release 10 (Nakamura, 2009), a base station with three sectors can provide a cumulative downlink throughput of 9.9 Gbps. Furthermore, according to the latest statistics provided by the Central Statistics Bureau of Kuwait, there are 1,970 houses (users) in Qortuba (CSBK, 2018). By multiplying the number of base stations by the capacity of each station and dividing by the number of users, we get the data rate per house. For 12 base stations in the whole area of Qortuba (current situation), the downlink data rate per house is given as

$$Data\ rate\ per\ house = \frac{9.9\ Gbps * 12}{1970} = 60.3\ Mbps\ per\ house$$

Dividing the average number of 4G users that was extracted from the MNO data in Table 2 by the number of houses, we will get the average number of users per house.

$$Average\ users\ per\ house = \frac{4625}{1970} = 2.35\ \ users\ per\ house$$

This will result in an average data rate per user of 25.66 Mbps.

To take full advantage of the proposed system, 43 base stations are needed to cover the whole area of Qortuba. The will lead to the following downlink data rate per house:

$$Data\ rate\ per\ house = \frac{9.9\ Gbps * 43}{1970} = 216\ Mbps\ per\ house$$

The average data rate per user will be 92 Mbps.

SIMULATION RESULTS

In order to simulate the proposed solution, we will be using a discrete event simulator called OMNeT++, an extensible, modular, component-based C++ simulation library and framework that is primarily used for simulating networks. On top of OMNeT++, we have installed two individual libraries. The first is INET Framework, an open source library that includes internet stack protocols such as TCP, UDP, IPv4, and IPv6. It also includes wired and wireless link layer protocols such as Ethernet, PPP, and IEEE 802.11. The second library is SIMULTE, which includes mobile network libraries to create such things as base stations, mobile users, VoIP applications, and other cellular-based functions like handover and device-to-device communication.

The simulation consists of two antennas. One is considered the base station and the other is the receiver antenna that is set up on top of the house. The other components are the Access Point (AP) and two routers, which will connect to the receiver antenna and provide one client with connection. A single server will be used as a media source. The devices have the following specifications configured in the OMNet++ Code. In the simulation, Antennas A & B (Full Dimension [FDD] MIMO +3D-BF), two routers with 10 Gbps throughput, and 802.11ac Wi-Fi are used. The simulation will be of a video streaming service where the client will stream the video through the wireless network from the server. The setup is configured as shown in Figure 5. Running the simulation yields a throughput of 7.9 Gbps per base station.

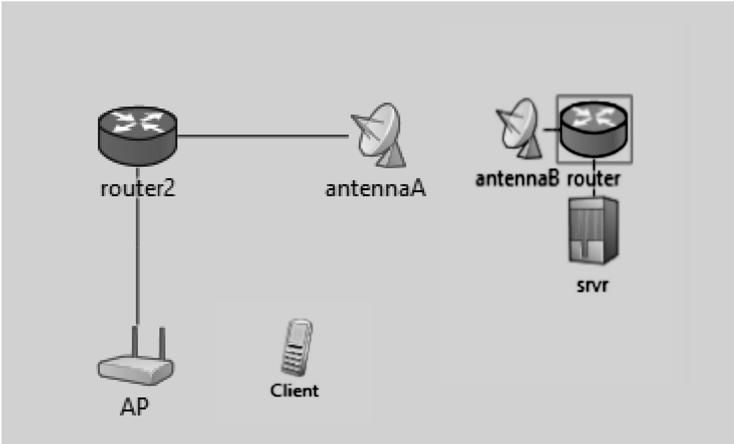

Figure 5. Simulation environment of the proposed network scenario.

For 12 cells in the whole area of Qortuba (current situation):

$$Data\ rate\ per\ house = \frac{7.9\ Gbps * 12}{1970} = 48.1\ Mbps\ per\ house$$

For 43 cells in the whole area of Qortuba to take full advantage of the MIMO system:

$$Data\ rate\ per\ house = \frac{7.9\ Gbps * 43}{1970} = 172.4\ \ Mbps\ per\ house$$

Given that there are on average 2.35 users per house, based on the proposed system, the data rates will reach 48.1 Mbps per house and 20.47 Mbps per user if the number of cells in Qortuba stays at 12. If the number of cells has increased to 43 to explore the full advantage of the MIMO system, a data rate of 172 Mbps per house and 73.36 Mbps per user can be reached. These data rates represent a substantial increase over the existing data rate of 5.33 Mbps per users, which is based on the data presented in Table 2 for 12 base stations. If the base stations of the current system are increased to 43, the expected data rate per user will increase by the ratio 43/12 to reach 19.1 Mbps. These results are presented in Table 3. Clearly, the proposed system provides much higher data rates. This substantial increase comes at the price of increasing the number of cells from 12 to 43 and using cell densification, MIMO, beam forming, and PTM technologies. In addition, the data rates obtained by the proposed system are much higher than the 27.33 Mbps average data rate in the U.S.A. reported in 2018 (Speedtest.net, 2018).

Table 3. Comparison of download data rates per user.

Scenario	12 base stations (Mbps)	43 base stations (Mbps)
Current average throughput per user	5.33	19.1
Theoretical average throughput per user	25.66	92
Simulation average throughput per user	20.47	73.36

CONCLUSION

In the paper, we have shown that the traffic through MNOs in Kuwait are increasing at an exponential rate and that there is an urgent need to improve the existing system to deliver an acceptable downlink data rate. By taking actual data from a typical residential area in Kuwait, Qortuba, it is found that current speeds are not even close to the minimum 4G LTE speeds. A proposed system is presented, which utilizes cell densification, MIMO, beam forming, and PTM technologies. The proposed system is simulated using OMNet++. The simulation resulted in speeds far exceeding the current actual speeds. The average throughput per subscriber was increased from 5.33 Mbps to 20.47 Mbps for the case, in which the number of base stations stayed at 12. On the other hand, if the number of base stations has been increased to 43 to exploit the full potential of the proposed system, the down load data rate will increase from 19.1 Mbps to 73.36 Mbps.

The downfall of the proposed system is the number of base stations required to cover an area of 1 Km^2. It is believed that a collaboration between Kuwait Public Authority of Housing, the Communication and Information Technology Regulatory Authority (CITRA), and MNOs must be made to provide enough space for base stations in future residential areas in Kuwait. We suggest that the Public Authority of Housing should provide MNOs with expected population and growth of each area, and in return MNOs will provide them with suggested coordinates of base stations. Another suggestion is that the ownership of the base stations should be assigned to CITRA, to limit the number of locations allocated to base stations needed by multiple MNOs.

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تحسين أداء الشبكة اللاسلكية في المناطق السكنية في الكويت

علي فيصل المطيري، يوسف البدر ومشعل الغربللي
قسم الهندسة الكهربائية، كلية الهندسة والبترول، جامعة الكويت

الخلاصة

ازداد استخدام البيانات على شبكات المحمول بشكل كبير في دولة الكويت حيث لم تعد سرعات شبكة الجيل الرابع الحالية تلبي احتياجات المستخدمين العاديين. وقد أدى ذلك إلى الحاجة إلى تحسين أداء النظام لزيادة سرعة تحميل البيانات. في هذا البحث، تم عرض ودراسة أداء شبكة الجيل الرابع المستخدمة حالياً ومواضع قصورها. وكذلك تم اقتراح نظام جديد يستخدم مفاهيم تكثيف الخلايا، والهوائيات متعددة المدخلات والمخرجات، وتشكيل شعاع الهوائي، وتقنية الاتصال من نقطة إلى عدة نقاط لتحسين سرعة تحميل البيانات في المناطق السكنية في دولة الكويت. تمت محاكاة النظام المقترح، وتم مقارنة أداء الشبكة القائمة والنظام المقترح باستخدام البيانات المقاسة الفعلية للشبكة القائمة والبيانات التي تم الحصول عليها عن طريق المحاكاة للنظام المقترح من حيث معدل سرعة تحميل البيانات. وقد تم التحقيق في أداء الشبكة اللاسلكية لمدينة قرطبة السكنية في دولة الكويت. أدى إدخال مفاهيم الأربعة السابقة إلى زيادة معدل البيانات بشكل كبير. استناداً إلى البيانات التي تم جمعها، يبلغ متوسط معدل بيانات المستخدم الحالي 5.33 ميغابت في الثانية. مع النظام المقترح، إذا تم الاحتفاظ بنفس العدد من أبراج الاتصالات (12 برج)، فإن معدل البيانات سيرتفع إلى 20.4 ميغابت في الثانية. إذا زاد عدد الأبراج (43 برج) لاستغلال الإمكانات الكاملة للنظام المقترح، فإن معدل بيانات المستخدم العادي سيزيد من 19.01 ميغابت في الثانية إلى 73.36 ميغابت في الثانية.