Passively Inferring Wireless Network Signal Quality from Different Data Resources

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Summary
Wireless signal quality is an important indicator to attract more customers and provide better service for cellular network operators. Cellular network operators and communication regulatory authorities usually do field experimentations to test the performance and service quality of their cellular network. These tests include drives test, signal level quality, tower power level measurements, etc. Customer satisfaction is an important driver for cellular network operators, and that includes their satisfaction on mobile data connections and IoT devices infrastructure in addition to phone call quality. Customer satisfaction assessment, most importantly, from the consumer's perception, is necessary to evaluate the network performance and maintain service quality standards. In this paper, we show that we can infer some service quality indicators for wireless cellular networks passively from previously collected data. We show that Received Signal Strength and Network Delay received during the mobility management field and data collection experiments can also be used to test and evaluate the performance of the wireless cellular networks.

Key words:
Signal Quality, Wireless Cellular Networks, Mobile App, Signal Strength, IoT Infrastructure.

1. Introduction

Wireless signal quality is an important indicator to attract more customers and provide better service for cellular network operators. Cellular network operators and communication regulatory authorities in every country usually do field experimentations to test the performance and service quality of their cellular network. These tests include drives test, signal level quality, tower power level measurements, etc.

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In this paper, we show that we can infer some service quality indicators for wireless cellular networks passively from previously collected data. We show that Received Signal Strength and Network Delay collected during the mobility management field and data collection experiments can also be used to test and evaluate the performance of the wireless cellular networks.

During the last seven years, we have been performing different data collection exercises related to mobility management of Hajj traffic in TCMCORE [10] and Umm Al-Qura University [11]. We have used two techniques to collect mobility data, mobile apps, and AVL devices. We used collected mobility data later to infer traffic and crowd mobility patterns and behaviors and build models. We discovered, nevertheless, that we are also collecting cell phone signal strength power levels and other quality measurement data such as Post Delay, which is the time difference between the time of sampling the data from the Mobile or AVL device and the time of posting this record into the database. In this paper, we are reporting our experience with such passive data collection exercises and reporting our findings related to wireless signal quality measurements collected. Our objective is to show how we can infer the quality of the cellular network passively from previously collected data.

The paper is organized as follows. In section 2, some related work is discussed, while in section 3, the methodology of our experimentations and data collection is provided. In section 4, we will show the results of our data collection exercises. Finally, a discussion on the whole experience will be given.

2. Related Work

The authors in [1], built a neural network model to passively estimate the GSM received signal strength using environmental parameters, mainly temperature. The results shown in the paper, suggests that the relation between weather conditions and received power signal can be indeed predicted using machine learning algorithms. In [2], the authors studied the effect of environmental conditions like altitude, fog, and humidity on the quality of the GSM signal. They concluded that fog has a powerful effect on GSM signal strength and that cell phone signal varies over

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time. The data were collected actively using specific measurement devices.
The authors in [3], conducted an experimental study to measure the wireless signal power for different network service levels using floating cars approach with a mobile app to measure data actively. They did the experimentations on a campus level using volunteer students. In [4], the authors demonstrate how user location and activity can be inferred from the received power signal. To do that, they collected data to study the stability of GSM signals over time and different positions and activities. In [5], cell phone performance measurements were used to plan better 3G coverage and services. In [6], they estimated the performance of uplink and downlink and

Fig. 1 Sample Mobile App used to collect Pedestrian Mobility Patterns

thus provide a methodology that can be

Fig. 2 RSSI Level Reporting Info Page

they were used for better planning as well. The authors in [7] used a floating car approach to collect the signal strength using a phone, scanner, and a receiver across their town. The comparison shows a good match of phone quality measurement and expensive dedicated devices.
In [8], the authors conducted a drive test using specific devices to measure eight performance metrics from the GSM network in their town. They have concluded with a recommendation to the local operator to improve signal quality in certain areas. In [9], the authors introduced an innovative solution to the problem of delay measurement using a measurement app on mobile phones.

3. Methodology

In our mobility management studies, we generally use two widely available off-shelf technologies, Mobile Apps and Automatic Vehicle Location (AVL) devices. Since we are collecting live data, a cellular data network connection is essential. We were able to passively collect and report cellular network signal strength with spatial-temporal data at the same time.
Using a mobile app, we measure spatial and temporal data to track the movement of the subject, either walking or driving a car. With a certain sampling rate, the mobile app will read the location from the GPS module, record the time and insert them into the database. This kind of mobile apps is used for tracking purposes, and it is useful for understanding the mobility patterns of individuals or vehicle drivers. As a side product, this mobile app was collecting the wireless signal strength and report in the database.
오류! 참조 원본을 찾을 수 없습니다. shows a sample mobile app implemented by our team to collect mobility data inside the Grand Mosque of Makkah during Hajj. Figure 2 shows the mobile info page to report the RX power and RSSI levels. RSSI levels can be reported in dBm or ASU units. ASU is the Arbitrary Strength Unit, and it is an integer value related to Signal Strength in dBm. There is an approximate formula that can be used to switch between ASU and dBm as follows:

$$dBm = -113+(2*ASU)$$

The second most common way of tracking mobility patterns for modeling purposes is through Automatic Vehicles Location AVL devices. An AVL device can be installed easily in any vehicle to track the mobility of that vehicle. During Hajj, AVL devices were used to locate twenty thousand buses used to transport 2.5 Million Pilgrims all over Makkah and Mashaer Area.
Using the two methods, we were able to collect many mobility patterns during the last seven years, which helped

us understand the mobility patterns for 2.5 Million Pilgrims coming to Makkah every year. Also, and as a by-product, we have collected and observed the cellular network signal power indirectly for different locations of Hajj areas. **오류! 참조 원본을 찾을 수 없습니다.** summarizes the location, technology used and mobility type for all experiments

4. Experimentation and Results

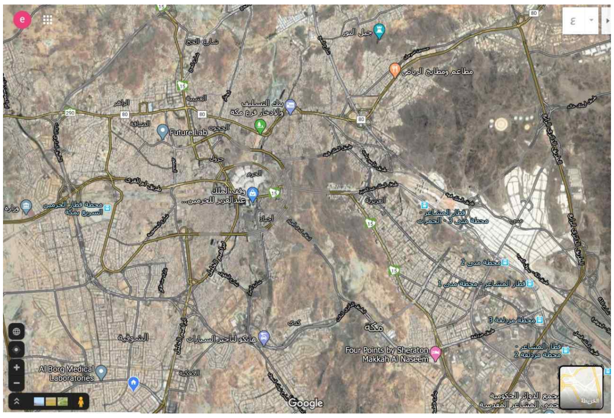

Fig. 3 Experimentation Locations Map within Makkah City

<u>Experiment 1: Collecting Mobility Patterns inside the Grand Mosque</u>

The grand mosque in Makkah contains the central icon that Muslim all over the world prays to 5 times every day. The Ka'abah is a black cubical shape structure that Pilgrims circulate seven times when they come for Hajj. During this experiment, we asked volunteers to carry mobile phones running a simple lab-made mobile app during their circulation around Ka'abah for seven consecutive days. Our interest was to collect the 'time needed to finish one complete circle around Ka'abah' during the entire day. We used that time to infer the level of congestion in that area. **오류! 참조 원본을 찾을 수 없습니다.** shows the developed mobile app, and Fig. 4 shows a sample of geospatial data collected from the grand mosque [14].

We used sim cards from the same operator company. Since the original objective was to measure movement behaviors inside the Grand Mosque, we did not care about using SIM cards from multiple operators.

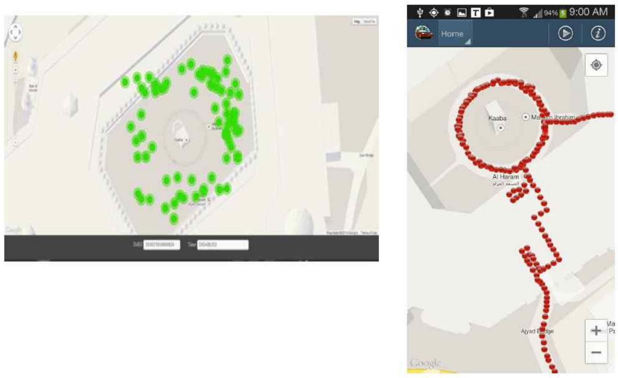

Fig. 4 Sample Collected Data in the Grand Mosque

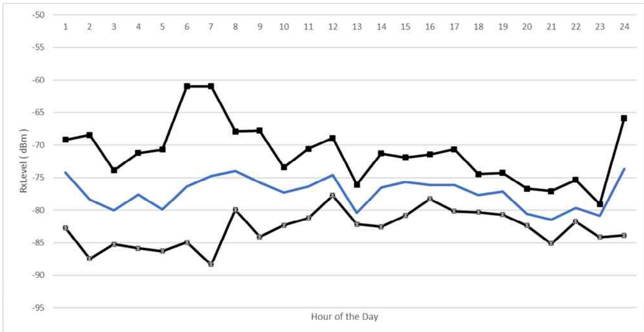

Fig. 5 Average, Maximum and Minimum RX Signal Strength in dBm during 24 hours in Expermint 1

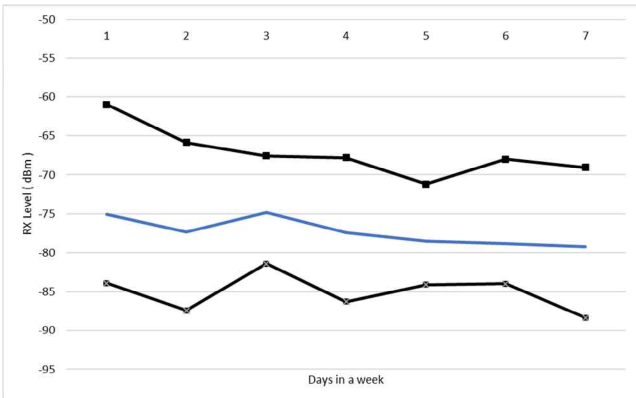

Fig. 6 Average, Maximum and Minimum Signal Strength dBm for each day

Fig. 5 shows the collected RX signal strength levels collected from the mobile apps as average, maximum, and minimum in dBm per hour averaged overall days. Fig. 6 shows the average, maximum, and minimum Rx Level in dBm measured for each day of the collection period. One can notice the fluctuation of received power signal during the day and during the week where it ranges from about

-60 dBm to -90 dBm at a specific time of the day. As a rule of thump, an RX signal strength value is -70 or higher. It indicates full signal; if the value lies between -70 to -75, then it indicates an optimal signal if the value lies between -75 to -85 dBm, then it indicates a fair signal. If the value is -85 or lower, then it indicates a weak signal. With the increased number of people around this area, a more rigorous quality check from cellular network operators is needed to ensure the best quality provisioning to the Grand Mosque visitors.

Experiment 2: Collecting Mobility Patterns on a significant Highway using drive tests

Using our developed mobile app shown in **오류! 참조 원본을 찾을 수 없습니다.**, we ask volunteers to collect congestion patterns on a major highway in Makkah called 3rd ring road using the drive test methodology. The in-city highway extends from the North-West corner of the city to the South-East corner on 21KM long, as shown in Fig. 7. We asked volunteers to drive at a constant speed as much as possible back and forth for the entire day. Our intent, again, was to estimate the congestion level and understand driver behavior on this major in-city highway.

We handed the volunteers similar smartphones with sim cards from the same operators. We asked them to hang the phones on rigid holders to unify the data collection exercise. We collected data 24 hours over eight consecutive days. To report the results in an aggregated way, we grouped data spatially and temporally. We divided the road into 1KM segments starting from the upper end on the map. At the same time, we grouped the data into 12-hour bins starting from 8 AM on the first day. The result is a 21x16 matrix shown in Table 1.

The reader can notice that segment number 7 has reported a weak signal compared to other segments on the same highway. This might be due to the mountains surrounding the 7th segment. There might be some other causes like inadequate coverage from the mobile operator in that region. However, with our existing data, we cannot conclude anything.

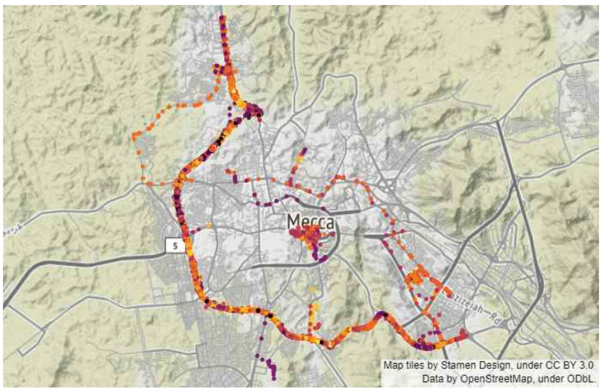

Fig. 7 3rd Ring Road

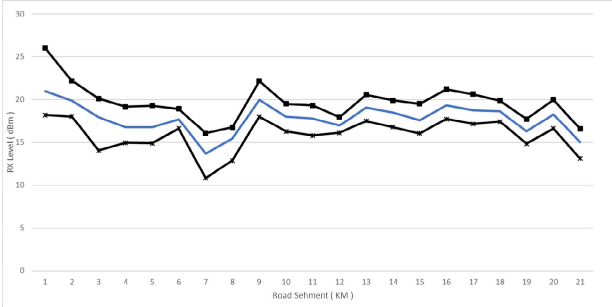

Fig. 8 Average, Max, Min ASU for RX Level

Experiment 3: Collecting Network Delay using from AVL Devices Data.

In 2016, it was ordered that all buses involved in Hajj transportation should be equipped with AVL devices to track their locations with a sampling rate of 30 readings per hour. Our lab was able to collect this data as part of the research collaboration. The collected data in the first season was reasonably big data with more than 40M records. We did some initial data analysis in this paper; however, with a lack of big data infrastructure, it was challenging to run advanced queries on this dataset. In our near future work, we are going to report more data analytics from this dataset.

We found interesting parameters that we could not find before in Mobile App data, i.e., Experiments 1 and 2. 2016 AVL data contained two date-time columns representing the 1) time of taking the reading from the moving vehicles and 2) time of posting that record in the database. Bus Companies used different mobile phone operators as their data providers, but, unfortunately, we could not have that information. Thus, this data could be beneficial to compare the performance of different mobile operators in terms of data upload network delay.

We extracted part of the data to be able to handle it easily. We selected the geographical area as in Experiment 2, which is the data related to 3rd Ring Road, which is a very busy road for bus traffic during the season. Fig. 9 shows an overview of the number of records counted per company in the selected geographical area. We removed the data of 4 companies, which showed unrealistic data, and thus we consider their data outliers.

We analyzed the data collected for Bus Company number 14 since it has the largest number of collected records per 1KM road segment as done in Experiment 2 before. Fig. 10 shows both the number of records per road segment and the time delay between taking the record on the AVL device and posting it into the database. Two things can be inferred from this figure. The first thing is the variation of several records between road segments and the variation of the delay as well. One can infer some useful information from this kind of data to evaluate mobile phone coverage and performance per road segment.

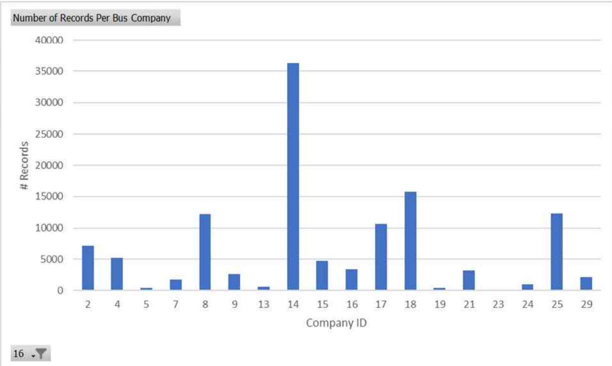

Fig. 9 An overview of the Number of Records in selected dataset per Bus Company

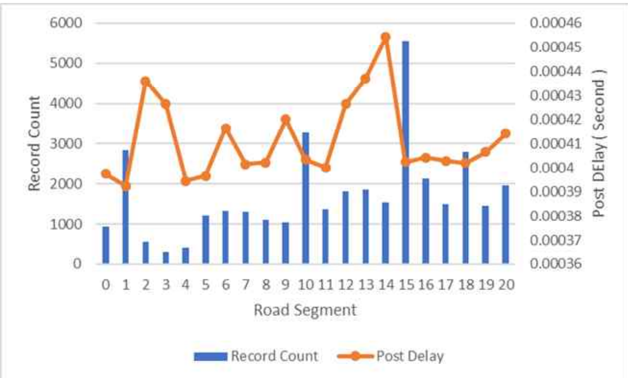

Fig. 10 Summary of Collected Data for Company 14

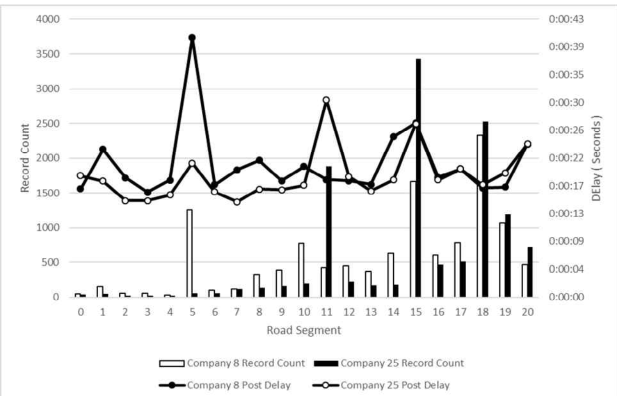

Fig. 11 Data comparison between two bus companies

Fig. 11 shows a comparison between two bus companies, 8 and 25. They both have a similar number of records. We combined both indicators, the number of records, and post delay in one graph to show the relation between them. Data from both companies shows a large post delay in road segment number 5.

We summarized the collected data in a tabular format shown in

Table 3. This table suggests that company number 16 had selected a very reliable mobile operator to carry their data from AVL devices to their databases while companies such as 13,14 and 15 selected the worse mobile data service every. We can also conclude that the mobile coverage in the 3rd ring has been improved compared to data in 2014 since we cannot quickly identify any blackspot created vs. road segment. Thus, the quality of the connection is dependent on the selection of the mobile data service provider.

6. Conclusion

In this paper, we analyzed previously collected data to infer some conclusions on the quality of the cellular network. We analyzed three datasets that were collected for mobility management research and behavior modeling. The first dataset was related to crowd mobility patterns, and the next two datasets were for traffic modeling. We used two technology to collect the data, mobile app on a smart phone, and AVL devices. We analyzed RX signal strength and post delay values to infer the quality of cellular network.

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Table 1: ASU Levels of different segments in 3rd ring road

12 Hours Block | Road Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	18.21	23.64	19.45	21.14	20.48	21.02	21.49	20.78	20.15	21.71	19.25	20.26	19.92	20.45	21.71	25.98
1	20.03	22.17	19.28	21.59	21.58	18.75	19.45	19.5	19.84	18.02	18.28	19.42	20.11	19.1	20.76	19.84
2	19.69	14.05	17.84	18.92	20.12	17.7	18.73	19.16	17.86	17.48	16.8	18.39	16.73	16.92	17.72	19.14
3	15.83	17.74	16.93	19.16	14.94	15.13	18.02	17.26	16.56	16.69	15.54	16.93	14.94	16.33	18.12	17.69
4	15.81	15.68	16.06	17.66	19.3	17.02	16.48	18.64	16.9	16.73	15.65	16.63	14.91	16.87	17.97	16.04
5	16.88	16.78	17.24	18.77	17.18	18.34	17.39	18.94	17.39	17.61	16.62	18.49	16.68	18.07	18.53	18.3
6	14.24	10.82	14.22	14.28	13.36	13.48	14.66	14.11	13.59	13.6	13.55	13.94	12.72	12.94	13.32	16.06
7	15.88	12.89	15.36	15.43	13.21	16.74	16.56	15.68	15.53	15.27	14.99	16.08	14.91	15.31	16.55	16.42
8	20.88	22.15	19.79	20.94	18.34	20.18	20.1	21.33	19.7	20.03	18.06	20.14	18.01	18.63	20.98	20.42
9	17.52	18.34	16.87	17.78	16.26	19.12	17.94	19.38	17.45	18.43	17.27	18.74	16.9	18.01	19.51	19
10	15.83	17.9	18.47	17.41	16.26	18.52	18.12	18.46	17.64	19.33	15.8	18.72	17.18	17.45	19.28	18.71
11	16.95	17.02	17.45	17.13	16.1	16.86	17.5	17.71	16.6	16.41	16.68	16.94	16.4	16.34	17.7	17.97
12	19.13	20.55	19.3	19.28	18.67	19.01	18.72	20.5	18.92	19.94	17.5	18.9	17.65	18.36	20.04	18.88
13	19.71	19.85	18.41	18.19	17.05	18.56	18.18	19.55	18.2	19.3	16.76	18.54	17.15	17.79	19.89	19.17
14	17.92	17.63	17.28	17.7	16.48	17.96	17.8	17.95	17.51	18.4	16.8	17.92	16.02	17.04	17.79	19.51
15	17.76	21.19	19.11	20.28	18.9	18.95	19.17	20.84	18.61	20.89	18.76	20.75	18.14	18.6	19.39	17.74
16	18.71	19.26	18.81	18.65	17.62	18.48	19.07	18.92	17.16	20.6	17.82	18.61	18.17	18.57	20.33	19.13
17	17.7	19.07	18.73	19.87	19.18	18.81	18.52	19.76	18.13	19.63	18.34	18.72	18.59	17.42	18.11	18.11
18	16.88	16.35	16.19	16.48	14.86	16.4	16.88	16.68	15.33	16.25	16.86	15.93	16.62	15.06	16.28	17.73
19	17.85	18.27	18.51	18.5	16.61	17.97	17.97	18.82	17.45	18.1	18.35	19.03	19.99	17.7	18.88	18.42
20	14.18	13.14	15.32	15.44	14.07	15.03	15.45	14.49	14.09	15.53	15.67	14.15	15.37	15.74	16.34	16.58

Table 2: List of data collection experiments

Experiment	Year	Location	Technology	Mobility Type	Reported data related to Cellular Network	# Records Collected
1	2014	Grand Mosque	Mobile App	Walking, Volunteers	ASU	100K
2	2014	3rd Ring Road	Mobile App	Cars, test drive	ASU	400K
3	2016	Makkah	AVL	Buses, Passive	Network Delay	4M
4	2018	Mashaer	AVL	Buses, Passive	Signal Level	480M

Table 3: Post Delay Data of Different Bus Companies vs Road Segment

Bus Company | Road Segment	2	4	5	7	8	9	13	14	15	16	17	18	19	21	23	24	25	29
0	0:00:15	0:00:15	0:00:47	0:00:20	0:00:17	0:00:20	0:00:47	0:00:34	0:00:44	0:00:05	0:00:10	0:00:24	0:00:24	0:00:17	0:00:46	0:00:34	0:00:19	0:00:16
1	0:00:17	0:00:21		0:00:21	0:00:23	0:00:21	0:00:44	0:00:34	0:00:38	0:00:04	0:00:14	0:00:28	0:00:28	0:00:20	0:00:31	0:00:32	0:00:18	0:00:16
2	0:00:16	0:00:19		0:00:25	0:00:19	0:00:30	0:00:49	0:00:38	0:00:41	0:00:06	0:00:17	0:00:23	0:00:23	0:00:23	0:00:48	0:00:39	0:00:15	0:00:17
3	0:00:17	0:00:14		0:00:24	0:00:16	0:00:19	0:00:33	0:00:37	0:00:40	0:00:04	0:00:11	0:00:19	0:00:28	0:00:18	0:00:35	0:00:32	0:00:15	0:00:12
4	0:00:20	0:00:14		0:00:21	0:00:18	0:00:21	0:00:44	0:00:34	0:00:42	0:00:03	0:00:14	0:00:19	0:00:25	0:00:21		0:00:37	0:00:16	0:00:14
5	0:00:21	0:00:19	0:00:36	0:00:21	0:00:40	0:00:19	0:00:40	0:00:34	0:00:42	0:00:06	0:00:18	0:00:21	0:00:35	0:00:22	0:00:22	0:00:27	0:00:21	0:00:16
6	0:00:21	0:00:16	0:00:41	0:00:18	0:00:18	0:00:19	0:00:45	0:00:36	0:00:40	0:00:04	0:00:16	0:00:20	0:00:26	0:00:19	0:00:21	0:00:31	0:00:16	0:00:14
7	0:00:20	0:00:15	0:00:23	0:00:18	0:00:20	0:00:21	0:00:43	0:00:35	0:00:40	0:00:05	0:00:17	0:00:19	0:00:28	0:00:19	0:00:35	0:00:36	0:00:15	0:00:13
8	0:00:17	0:00:15	0:00:42	0:00:20	0:00:21	0:00:18	0:00:44	0:00:35	0:00:41	0:00:05	0:00:14	0:00:19	0:00:22	0:00:19	0:00:35	0:00:31	0:00:17	0:00:13
9	0:00:33	0:00:16	0:00:36	0:00:21	0:00:18	0:00:20	0:00:45	0:00:36	0:00:41	0:00:04	0:00:15	0:00:20	0:00:27	0:00:19	0:00:20	0:00:34	0:00:17	0:00:14
10	0:00:35	0:00:17	0:00:46	0:00:19	0:00:20	0:00:20	0:00:43	0:00:35	0:00:41	0:00:04	0:00:17	0:00:19	0:00:25	0:00:20	0:00:33	0:00:33	0:00:17	0:00:16
11	0:00:18	0:00:18	0:00:40	0:00:21	0:00:18	0:00:23	0:00:43	0:00:35	0:00:41	0:00:04	0:00:15	0:00:24	0:00:22	0:00:19	0:00:31	0:00:33	0:00:31	0:00:15
12	0:00:20	0:00:16	0:00:49	0:00:21	0:00:18	0:00:19	0:00:46	0:00:37	0:00:41	0:00:04	0:00:12	0:00:17	0:00:26	0:00:18	0:00:41	0:00:35	0:00:19	0:00:13
13	0:00:26	0:00:16	0:00:34	0:00:18	0:00:18	0:00:21	0:00:44	0:00:38	0:00:41	0:00:05	0:00:16	0:00:19	0:00:26	0:00:18	0:00:43	0:00:36	0:00:17	0:00:13
14	0:00:25	0:00:19	0:00:45	0:00:21	0:00:25	0:00:21	0:00:47	0:00:39	0:00:40	0:00:04	0:00:18	0:00:28	0:00:28	0:00:19	0:00:28	0:00:35	0:00:18	0:00:13
15	0:00:24	0:00:20	0:00:37	0:00:19	0:00:27	0:00:20	0:00:42	0:00:35	0:00:42	0:00:04	0:00:35	0:00:16	0:00:25	0:00:21	0:00:36	0:00:34	0:00:27	0:00:14
16	0:00:17	0:00:15	0:00:32	0:00:20	0:00:19	0:00:20	0:00:52	0:00:35	0:00:42	0:00:04	0:00:13	0:00:14	0:00:22	0:00:18	0:00:34	0:00:33	0:00:18	0:00:14
17	0:00:20	0:00:16		0:00:20	0:00:20	0:00:20	0:00:45	0:00:35	0:00:40	0:00:04	0:00:17	0:00:15	0:00:28	0:00:24	0:00:38	0:00:33	0:00:20	0:00:14
18	0:00:18	0:00:15	0:00:36	0:00:18	0:00:17	0:00:16	0:00:46	0:00:35	0:00:41	0:00:05	0:00:15	0:00:13	0:00:22	0:00:19	0:00:40	0:00:34	0:00:18	0:00:10
19	0:00:22	0:00:20	0:00:36	0:00:24	0:00:17	0:00:23	0:00:44	0:00:35	0:00:40	0:00:04	0:00:21	0:00:14	0:00:30	0:00:19	0:00:50	0:00:33	0:00:19	0:00:14
20	0:00:30	0:00:23	0:00:36	0:00:17	0:00:24	0:00:20	0:00:45	0:00:36	0:00:42	0:00:04	0:00:21	0:00:15	0:00:34	0:00:20	0:00:37	0:00:30	0:00:24	0:00:15