Efficiency of Wireless Local Area Networks in Clients Moving at High Speed

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Abstract. Wireless communication structures based on the IEEE 802.11 Standard became an important research area within science and economy during the last years. It forms a basis for an area-wide use of mobile services and personalized information within so called hotspots. However, the common usage is a public available stationary installation like at an airport, office building or university. Besides other wireless technologies like DECT or HiperLAN this paper shows, that Wireless LAN is capable for use in clients moving at high speed. To prove the theory a couple of measurements have been made using components of the IEEE 802.11b standard and clients moving at speeds up to 200 km/h. Beside measuring characteristic parameters like signal- and noise level as well as data throughput for different speeds, measurements on the quality of voice transmission have been made for the first time. In addition to a detailed analysis this article covers perspectives for applications using wireless hotspots.

1 Introduction

Wireless LAN relies on the IEEE 802.11 standard [3] which became one of the biggest economy areas for communication technologies in the last few years. In addition to a usage within desktop computers and notebooks as connection to wireless networks nowadays a majority of devices like PDAs and Tablet PCs supports such networks directly.

Most installed wireless networks use the IEEE 802.11b standard as supplement of the original IEEE 802.11 which was standardised in 1999 with a maximum transfer rate of 11 MBit/s and transmitting in the license-free 2.4 GHz ISM Band (Industrial, Science and Medical Band). The up-and-coming supplements IEEE 802.11g inside the 2.4 GHz Band as well as the IEEE 802.11a in the 5 GHz Band support higher transfer rates up to 54 MBit/s and will replace the IEEE 802.11b more or less fast in the future.

Within this paper some terms concerning wireless communication are used of which a definition is mandatory. Therefore, a short explanation of the most important will be given:

Client, Server and User. The term *Client* or *User* in relation to wireless communication is often a synonym for the service-consuming end-device. The server provides this services used by a client. Both, the client as well as the server are using the wire-

T. Böhme et al. (Eds.): IICS 2004, LNCS 3473, pp. 38–48, 2006.

less communication network, but no statement about mobility is associated with one of them.

Ad-Hoc-Mode, Infrastructure-Mode, Hotspot and Access Point. Within the standard IEEE 802.11 two network topologies can be distinguished. In an ad-hoc mode network clients build point-to-point connections between each other. Disadvantages of this kind of topology are the small amount of clients that can communicate and the low scalability. Furthermore a communication between two clients is impossible in case their distance to each other is to small even in the case a third station resides in between and could work as router.

The noted disadvantages do not arise in the infrastructure network. It uses a special device, the Access Point, placed in the centre of a starlike topology to manage all the communication. This means there is no direct connection present between the clients as mentioned for the ad-hoc-network. Each Access Point controls a Wireless LAN cell defined by the physical range of its emitted radiation. Different cells can be combined to cover greater areas. An advantage of this combination is the possibility to hand-over connections between proximate cells. All communication data is send from the actual Access Point to the next using a hand-over protocol (e.g. the Inter Access Point Protocol – IAPP).

Additionally, to achieve a connection between two fixed networks in greater distance, the IEEE 802.11 standard contains bridge-mode functionality.

The availability of wireless networks in public areas lead to the definition of such an accumulation of wireless cells as *hotspot*. A hotspot is a not necessarily contiguous area providing the same wireless network using the IEEE 802.11 infrastructure mode topology. The amount of Access Points within a hotspot is insignificant.

Mobility. As already noted, the definition of a client or server does not associate the mobility as property. In case it is included into the functionality, this leads to some categorization shown in figure 1:

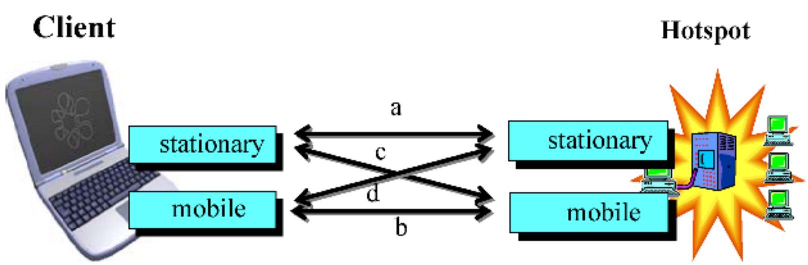

Fig. 1. Mobility as new Characteristic for Client and Hotspot

While in category a) both hotspot and client are stationary, e.g. when providing wireless access to workstations without the need of wires, the categories b) and c) can be found in the area of ad-hoc networks mostly.

This paper covers the evaluation of application fields for mobile clients in stationary hotspots (referred to as category d). Many public hotspots belong to this category, however their mobility is widely restricted. Our evaluation will cover clients moving at high speeds starting at 100 km/h. For this, a comparison with other technologies like GSM, DECT or HiperLAN is useful. Table 1 shows this technologies together with WLAN. Particularly interesting is the maximum speed by user which is high with 250 km/h and GSM but rather low for HiperLAN at 10 m/s.

Table 1. Comparison between wireless communication technologies [10]

Standard	GSM	DECT	WLAN 802.11b,g	HiperLAN
Band	900/1800/1900 MHz	1900 MHz	2,4 GHz	5,15-5,25 GHz
Bit Rate	270,8 KBit/s	1152 KBit/s	1-54 MBit/s	> 20 Mbit/s
Amount Carrier	125	10	14 maximum (differs regional)	
Channels per Carrier	8	24 (12 duplex)	variable	
Cell Size	< 35 km	< 400 m	Indoor < 50 m Outdoor < 500 m	Indoor < 50 m Outdoor < 500 m
Speed by User	< 250 km/h	< 50 km/h	Evaluated up to 90 km/h	< 10 m/s <36 km/h

This paper sets up on measurements with speeds up to 90 km/h in [7]. An important result of that paper is, that no significant interference for speeds up to 90 km/h could be evidenced. Therefore, section 2 covers the description of the testing range and specifies the used equipment for the measurements starting at 100 km/h in detail. Afterwards the test scenarios as well as the measurements will be described in section 3. Finally, section 4 summarizes all measured data and shows perspectives for applications.

2 Test Area and Test Scenarios

2.1 The Test Area

In the planned measurements, speeds up to 200 km/h should be achievable. Therefore, a part of a public highway as graphically shown in figure 2 is used. For the measurements, seven access points have been distributed along the highway part. The access points AP1 to AP3 are responsible for building the local hotspot for the moving client. AP4 and AP5 as well as AP6 and AP7 build a directed radio link to integrate the access points AP1 and AP3 into the communication network. The access point AP2 is connected to the network using a 100 meter wired connection. The stationary server is connected by wire too. Topologically a hotspot with three WLAN cells has been build, where the inner distance between the access points is 700 meters.

Technical Characteristics. For the measurements components from Enterasys Networks are used. The outer access points AP1 and AP2 as well as AP6 and AP7 are R2- Access Points using two wireless interfaces. While the first interface (AP1 and AP6) builds the wireless cell for the local hotspot using a 7dBi omnidirectional antenna, the second wireless interface (AP2 and AP7) is used to create the radio link to the centre station using a 14 dBi Yagi-Antenna.

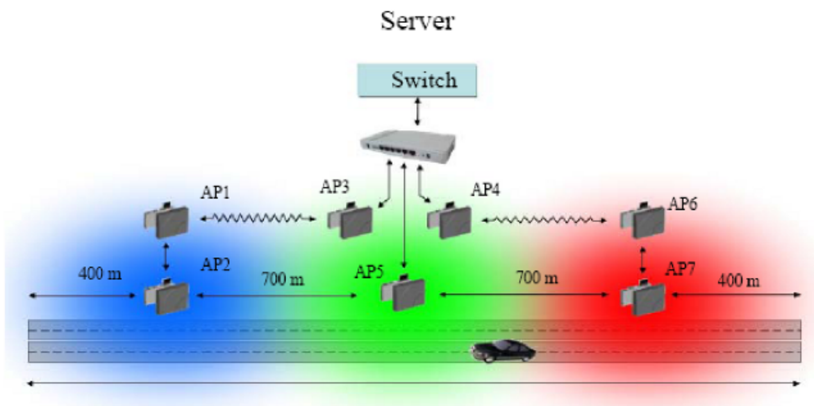

Fig. 2. Testing range at the highway

Because of the high antenna gain and thus too high emitted radiation above 100 mW E.I.R.P (Effective Isotropic Radiated Power) an adapted interface card with reduced power is used for the directed radio links. Besides the Access Points AP3 and AP4 as end points of the radio links at the centre station, AP5 builds the third infrastructure mode WLAN cell for the hotspot.

The wiring of the network itself has been done using a 100 MBit/s switch that connects the end points of the bridges as well as the centre Access Point and the server. For the server a notebook with 100 MBit/s LAN and Windows 2000 is used. The Client inside the car uses Windows 2000 as well as a wireless device with a 5 dBi omnidirectional antenna for in-car-use.

2.2 Measurements at Different Speeds

To evaluate network characteristics during a test run, measurements of parameters of the wireless connection as well as the possible data throughput are made starting at speeds from 100 km/h. Therefore, the mobile client moves along the testing range with constant speed.

The Connection-Quality. To get exact measurements of the connection quality, the software *Network Stumbler* (Version v0.3.30) [9] is used. An advantage compared to the Roamabout Client Utility used in [7] is a more exact logging of important parameters like signal and noise level as well as the resulting signal-to-noise ratio (SNR).

The Data-Throughput. The measurement of characteristic parameters of a wireless connection is no indication for the characteristic of the build data connection. Therefore [7] uses a software based on a round-trip-algorithm that collects characteristic information using a TCP-connection. This information is logged and evaluated.

As this tool does not allow an evaluation on site, our measurements uses the software *NetIQ Chariot* (Version v4.3) [9]. It allows to control the measurements by scripts and allows to measure TCP and UDP data. The used version of *NetIQ Chariot* contains standard scripts, whereas for measurements of the maximum available data-throughput the script `Throughput.scr` can be used. It creates random data with an exact size of 100,000 Byte and transmits them to the client while it moves along the testing range. The data packet size is limited to 32,767 Byte for TCP and 8,183 Bytes for UDP (induced by the used standard script).

All measurements for different speeds are repeated several times to discard measuring errors. In parallel to the evaluated data-throughput, the quality of the connection is logged.

The Behaviour During the Roaming. The behaviour of a wireless connection during the roaming process is measured using the *RoamAbout Client Utility* (Version v2.69) as well as the network analyse software *NetIQ Chariot*. Major disadvantages of the client utility is the low precision for the measured values and the measurement time with approximately four values per second. More detailed measurements are possible with *NetIQ Chariot*. Therefore a new script is created that measures the needed time to transfer 20 packets of exactly 100 Byte using TCP or UDP. This allows conclusions about the latency during the roaming process. A reduction of the amount of packets during the transmission is not possible due to the used software.

2.3 Measurements of Voice-over-IP

Positive results in [7] up to 90 km/h for TCP-connections suggest a possible use of Wireless LAN as media for Voice-over-IP connections. Therefore, two different scenarios are implemented.

In the first scenario, the analyse software NetIQ Chariot is used with a special Voice-over-IP packet that simulates typical voice transmissions to analyse influences of higher speeds on the transmitted voice. Therefore, the client inside the car is defined as a performance end-point to measure a single voice communication channel. To account for high traffic, three different speed ranges GB1 to GB3 are used, whereas the ranges are defined as follows:

- GB1 – 70 km/h to 100 km/h,
- GB2 – 100 km/h to 140 km/h, as well as
- GB3 – 140 km/h to 170 km/h.

To analyse the quality of a Voice-over-IP-Transmission mainly network- and speechchannel parameters are responsible. The used transmission rate is adapted by the Access Points. This allows rates from 1 MBit/s to 11 MBit/s. The Voice-over-IP Add On of NetIQ Chariot is initialized with the following parameter:

- Used Codec: ITU G.711 A-Law (G.711a)
- Framesize per packet: 30 ms
- Multimedia Transmission Protocol: RTP over UDP
- No Support for Quality of Service (QoS)
- Di-Jitter Buffer (ITU-Recommendation): 60 ms
- Initial Delay-Value: 0 ms
- No Transcoding
- Total Codec-based Delay by ITU G.114: 91 ms (includes Di-Jitter Buffer, Frame Size and Execution-Delay)

To analyse the quality three different methods are used, and can be classified into three phases:

- Phase 1 – without Silence Suppression and Packet Loss Concealment (PLC)
- Phase 2 – with Silence Suppression and PLC, as well as Voice Activity Detection (VAD) Rate of 50% (default value)
- Phase 3 – with Silence Suppression and PLC as well as additional UDP-traffic, the VAD rate is 50% again. To simulate additional UDP-traffic exactly 100.000 Byte of Data has been transmitted between Server and Client, while moving along the testing range.

In the second scenario a subjective reflection of the voice quality is achieved by using Microsoft Netmeeting. Therefore a real voice-channel is created between the server and the client inside the car. In opposite to the first scenario, the speed varies between 90 km/h and 150 km/h. The Netmeeting tool uses the CCITT A-Low Codec with 8000 Hz and an 8-bit mono-recording connection. This relies to the Codec G.711a. Further configurations are not tested here, but measurements show, that Netmeeting uses a framesize of 32 ms per packet.

3 Evaluation of the Measurements

The described scenarios in section 2 are used in practical measurements to evaluate the characteristics of WLAN in high speed vehicles. To evaluate the results, correlations between the measured values and outer influences must be considered. This influences can be high traffic which prevents a constant speed in some cases, as well as numerous vehicles that become obstacles and lead to significant signal reduction (named as Shadow fading in [10]).

3.1 Evaluation of the Connection Quality

During the measurements between 100 km/h and 170 km/h no direct dependence is recognized between the speed as well as the signal- and noise level. The noise level is measured with minimal deviations at -100 dBi. The signal-to-noise ration (SNR) equals to about 45 dBi in direct line of sight to the access point. An overlap of the three WLAN cells is noted at about 20 dBi. Figure 3 shows the connection quality at a speed of 100 km/h. Figures of other speeds do not show significant differences and are omitted.

3.2 Evaluation of the Data Transfer-Rate

All measurements of the data transfer-rate are done using the network analyse software *NetIQ Chariot* and start at 100 km/h. Consecutively, measurements of 130 km/h, 150 km/h and 170 km/h are done. Because of high traffic measurements with higher speeds up to 200 km/h can be evaluated temporarily only. Therefore, they are not covered by this paper. Corresponding to section 3.1 no significant influences of the speed are recognized. Table 2 shows the average data transfer-rate for the mentioned speeds.

During all measurements no complete loss of connection happens even at a speed of 170 km/h. Therefore, a wireless connection is even possible that this speed. As mentioned in table 2, the deviation of the average data transfer rate is subject to minimal variations only. This leads to no conclusion regarding influences of the speed at the data transfer-rate. In fact it is interesting that the data transfer rate measured while moving is about 25% lower than for fixed measurements. Variations can by means be described with environmental influences.

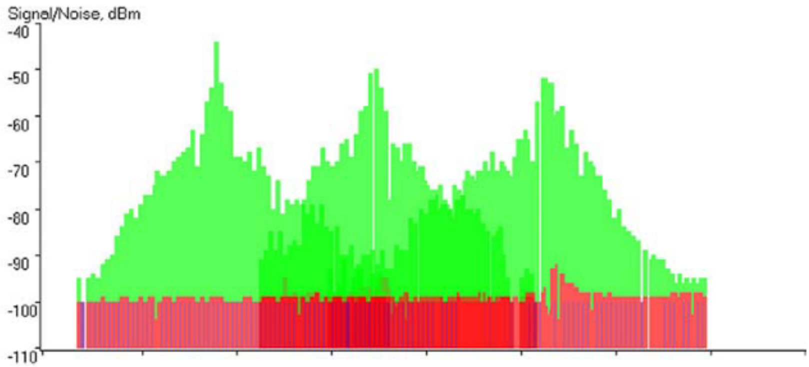

Fig. 3. Connection Quality at 100 km/h, Network Stumbler

Table 2. Average Data throughput for UDP and TCP at different speeds

Velocity	UDP (Mbit/s)	TCP (Mbit/s)
100 km/h	2,8	3,3
130 km/h	2,6	3,1
150 km/h	2,5	2,7
170 km/h	2,6	3,0

3.3 Evaluation of the Roaming Process

The measurements to determine the time of a roaming process are done by sending and receiving 20 packets á 100 byte size. By means of the differences between the measured times while moving along the testing range and during the roaming process an average roaming time can be derived. A transmission of data is impossible during the cell change. Table 3 shows the measured average roaming time for TCP and UDP-connections at different speeds.

The fluctuation of this values leads to a very common conclusion only. While for TCP the roaming time in average is significant lower for higher than for lower speeds, it increased at 190 km/h to its triple value. The measurements of UDP are not subject of this kind of fluctuations. Measurements of other speeds show analogical results. This leads to a necessity of a higher granularity within the measurements to gain more exact conclusions. A direct influence of the speed on the roaming cannot be proven by this measurements.

In consequence of the small size of the packets and its frequency of occurrences, table 4 shows a significantly lower data transfer-rate than measured previously. Nevertheless, the deviation of the average is lower. Clearly visible is the approximately 25% lower data rate of the outer Access Points due to their connection via wireless bridge.

Table 3. Differences of times during the roaming

Velocity	UDP (ms)	TCP (ms)
130 km/h	386	476
150 km/h	423	240
170 km/h	399	265
190 km/h	426	814

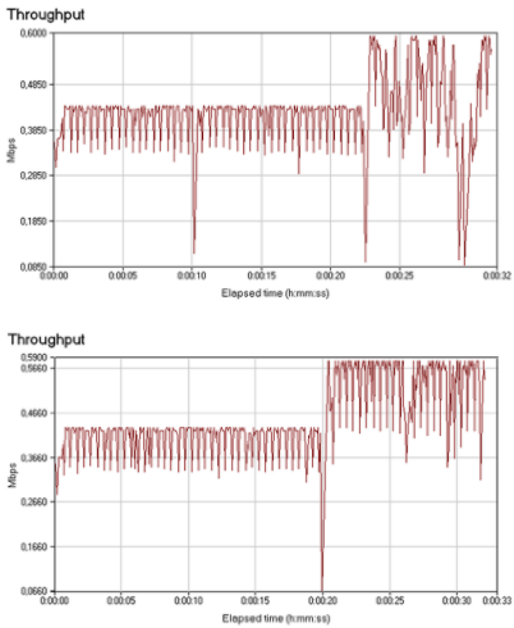

Fig. 4. Roaming at 170 km/h for TCP (top) and UDP (bottom)

3.4 Evaluation of Voice-over-IP

The measurements for Voice-over-IP are divided into two separate scenarios. The results of these scenarios are presented here.

3.4.1 Voice-over-IP Simulation Using NetIQ Chariot

All tests results are shown in table 4. Because of the asymmetric character of the speech channel, the average of the parameters are computed separately from the corresponding single values for both directions. It must be pointed out, that there are excellent results in test case B. All in all the measured values are similar as those gained from static network connections. Although the packet loss exceeds the limit of 1% as specified by the ITU. Therefore an use of PLC at the receiver must be taken into account[12][13]. The resulting speech quality is very good with a MOS-Score above 4.0 with and without additional data transfer (test case D). Our measurements show, that additional data transfer influences the delay significantly but does not have a bearing on the quality of speech and packet loss.

Table 4. Evaluation of Voice-over-IP Measurements

test cases		A	B	C	D
		Speech Channel: G.711a-Full Duplex			
		GB1 + Phase 1	GB2 + Phase 2	GB3 + Phase 2	GB2 + Phase 3
		without VAD/PLC	with VAD/PLC		VAD/PLC and UDP-data
Speed in km/h (min. - max.)		70 - 100	100 - 140	140 - 170	100 - 140
Average data-throughput		117,208 KByte/s	36,512 KByte/s	35,336 KByte/s	2244,464 KByte/s
One-Way-Delay		5 ms	2 ms	4 ms	15 ms
End-to-End-Delay		96 ms	93 ms	95 ms	106 ms
Jitter (Delay Variation)	min. - max	0 ms - 60 ms	1 ms - 20 ms	2 ms - 42 ms	9 ms - 135 ms
	< 11 ms [%]	94	96	96	68
Packet-Loss [%]		1,67	1,045	1,8	1,62
Speech-Quality	Average MOS	3,7	4,2	4,1	4,1
	Consumer satisfaction	some consumer unsatisfied	satisfied	satisfied	satisfied
	Category of quality	average	high	high	high

A direct influence of the speed on any Voice-over-IP communication cannot be proven, even with the worse results in test case C comparing to test case B. Reasons for this worse case can be put down to the dynamically change in the traffic on the highway. In difference the roaming process significantly influences the speech quality in case of additional data communication (test case D).

Below the different measured values shown in table 4 are described in more detail.

Delays. All measurements do not show any influences between speed and measured delay values. In test case D the delay is higher in consequence of the additional UDP data transfer, because of a higher delay in queues and during the serialisation [15]. However, the end-to-end-delay continuously stays between 150 ms as recommended by the ITU [17]. Any influences of the roaming could not be proven, but the measured delays below one millisecond in the test cases A and B are rather interesting.

Jitter. The jitter of incoming packets as shown in table 4 in the case without any VAD is higher, because of the higher amount of speech data to transmit. [13][14]. Nevertheless, 94% of all jitter is lower than 11 ms (in test cases B and C actually 96%). Influences of the speed cannot be proven. Any data transmission raises the runtime deviation because of higher delays within queues. Therefore test case D shows a jitter between 9 ms and 135 ms, which is twice the Jitter-Buffer and corresponds to an End-to-End- Delay up to 181 ms. Consequently this leads to frequent interrupts during a conversation as well as losses of connection [13][17]. Influences of the roaming is noticeable too, but very low. In test case D the runtime jitter lies between 9 and 30 ms, but subsides instantly after the roaming. Other test cases do not show any influences at all.

Data Throughput of Speech Data. For analysing speech data, row data without any protocol overhead is taken into account. The measurements show, that a consequent use of Silence Suppression leads to a significant reduction of used bandwidth. Therefore, test case C shows an about 70% lower amount of data as test case A. No influences of speed and roaming are visible. A variation of the data throughput over all test cases cannot be recognized in the graphical representation.

Packet Loss. By recommendation of the ITU packet los shall not exceed a limit of one percent [13]. All measurements results in higher values. This is mirrored directly in the MOS-Value for the speech quality in test case A which is about 3.7. The use of PLC within the G.711a Codec leads to significant better results in face of a packet loss of 1.8% in test case C. The result was a quality of speech of about 4.1 (MOS). Influences of the roaming are very light. Test case D shows interesting results with no packet loss during the roaming when moving from the eastern access point to the central but a significant higher value of 3% when moving between the central access point and the western access point. This leads to a reduction of the speech quality of 4.37 to 4.1. The packet loss is recognized in bursts, where half of all sent packets are single packets.

Speech Quality. An important factor while evaluating Voice-over-IP is the speech quality. Recommendations of the ITU for G.114 and G.131 demand a minimal quality of 3,6 in the MOS-Score for speech communication systems [17][18]. All test cases achieve this value in average, however high variations can be recognized. For the test case A the MOS-Score varies between 2,2 and 4,37, while test case B has excellent results between 4,1 and 4,37.

3.4.2 Subjective Evaluation of the Speech Quality Using Microsoft Netmeeting

A subjective evaluation using Microsoft Netmeeting leads to a very positive result. Even at a speed of 200 km/h a communication is possible without any complications. Not until high distances (partly over 500 m) to an Access Point and with a SNR-Value clearly below 10 dBi a communication interrupt appears.

Any short timed interrupts during the roaming cannot be recognized subjectively. Refer to the simulated communication how far the influence on the transmission is.

4 Summary and Perspectives

The provided measurements for evaluating the efficiency of mobile clients in wireless networks based on IEEE 802.11b clearly show, that even at speeds up to 200 km/h a data transmission and therefore a use of different services is possible. This is essential for connections using UDP as well as TCP. All measurements take place in an environment with real-time conditions at a public highway and thus high traffic. To gain meaningful results and to eliminate errors multiple measurements are done. A direct influence of speed on the wireless network, physically founded by the arising Doppler-Effect cannot be proven. A consequence leads to the assumption of a very good adjustment of the used wireless hardware to this kind of frequency variations.

However, the results show, that outer influences, like obstacles in direct line of sight between the Access Point and Client (e.g. trucks) have significant impact on the signal level and commonly lead to a loss of the communication stream. Further measurements for more detailed results in this so called shadow fading, are planed.

In case of measurements to evaluate the quality of speech transmissions (Voice-over- IP) within WLAN systems again no direct influence of the speed can be found up to 200 km/h. However, the used codec should support PLC and VAD to improve the quality.

Comprising, the results can be categorised as encouraging for the realization of new architectures based on mobile clients for data as well as for speech transmission.

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