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Call Admission Control Scheme for Improved Quality of Service in WiMAX Communication at Vehicular Speeds

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Abstract— The IEEE 802.16e standard, also known as mobile WiMAX, has emerged as an exciting mobile wireless communication technology that promises to offer both high throughput and guaranteed quality of service (QoS). Call admission control (CAC) scheme serves as a useful tool for WiMAX, which ensures that resources are not overcommitted and thereby, all existing connections enjoy guaranteed QoS. Existing CAC schemes largely depend on readily available information like currently available resources and bandwidth demand of the new call while making an acceptance or rejection decision once a new request arrives. Since wireless channels are not as reliable as wired communication, CAC scheme in WiMAX communication faces a serious challenge of making a right estimate of the usable channel capacity (i.e., effective throughput capacity) while computing the available resources in various communication scenarios. Existing CAC schemes do not consider the impact of mobility at vehicular speeds when computing the usable link capacity and available resources. In this paper, we propose a new CAC scheme that estimates the usable link capacity for WiMAX communication at various vehicular speeds and uses this information while making a CAC decision. The proposed CAC scheme takes the speed distribution model of a mobile node into account during the CAC decision making process. Simulation results confirm that the proposed scheme achieves lower dropping rate and improved QoS compared to existing schemes.

Keywords- Mobile WiMAX, vehicular speeds, usable channel capacity, QoS.

I. INTRODUCTION

Wireless communication has enjoyed an extraordinary growth in the past decade and wireless devices are now an integral part of our daily life. The IEEE 802.11 standard [1] has been the pioneer wireless communication technology and a huge commercial success. Despite the widespread penetration of the 802.11, the need for further improvement in the wireless data transmission rate and QoS was realized, which has led to the introduction of another family of standards, termed as the IEEE 802.16 [12]. Many researchers today advocate the IEEE 802.16, also commonly known as WiMAX, as the futuristic solution to wired broadband infrastructure for hard-to-reach areas like rural or urban places. A key feature of the WiMAX technology is its ability to offer guaranteed QoS.

Features like traffic classification, connection oriented service and tools like QoS-aware media access control (MAC) scheduler and CAC schemes have been adopted in the 802.16 family of standards as mechanisms to deliver guaranteed QoS to the end applications. The CAC scheme plays a crucial role in QoS provisioning in the 802.16 family. WiMAX uses connection oriented MAC and all subscriber stations (SS) need to request for a connection to the base station (BS) before they can actually transmit/receive any data. The BS upon receiving the request checks whether the available resources are sufficient to support the requested service without degrading the QoS for other continuing connections. This process of proactive action is governed by a scheme known as the call admission control or CAC. One of the fundamental working principles of all CAC scheme is that, in QoS-aware communication, high blocking rate is preferred over high dropping rate. Because of the importance of CAC schemes in QoS provisioning, researchers have been working to design an improved CAC schemes for WiMAX communication.

Wang *et al.* [2] proposed a dynamic CAC for the fixed 802.16d standard that uses bandwidth reservation and degradation policies. Bandwidth reservation is governed by traffic priority and degradation is the method of decreasing the bandwidth allocated to admitted connections once the useful channel capacity decreases. Initially when the available channel capacity is in the higher side, connections are given the maximum amount of bandwidth. Bandwidth per connection is gradually decreased as the number of connections increases, resulting graceful degradation of QoS. This CAC scheme was designed for fixed WiMAX and the authors did not consider the impact of mobility on usable channel capacity when a decision is made during the CAC process. Wang *et al.* [3] proposed a CAC scheme for the 802.16e standard, which assigns higher priority to the handoff connections compared to the newly originating connections using guard channel schemes. Ge *et al.* [4] proposed another CAC scheme for the 802.16e standard, that uses the bandwidth degradation model and admits a newly arriving connection only when no admitted connection is degraded and requested bandwidth is met. Rong *et al.* [5] proposed a CAC scheme for WiMAX communication that adopts two separate policies for admitting uplink connections and downlink connections with an aim of increasing the fairness and utility of connections. In

[6] and [7], the authors proposed scheduling algorithms that complement CAC schemes for improved services in the 802.16d standards.

All of the above mentioned CAC schemes considered currently available bandwidth as a part of CAC decision making process on whether to accept or reject a newly arriving incoming call. One of the major problems with mobile WiMAX communication is that usable throughput (defined as the effective throughput in bps received by the receiver) between the SS and BS becomes significantly low when the subscriber station (SS) moves at vehicular speeds. A CAC decision that is made based on available throughput, computed when the SS moves at a lower vehicular speed (or at a stationary position), may prove very costly when the SS will reach its top speed. To the best knowledge of the authors, none of the existing CAC schemes considered this issue of low usable throughput at high vehicular speeds while making a CAC decision. In this work, we have shown that an estimate of usable throughput at various vehicular speeds can be made in advance in WiMAX communication and, based on this information and speed distribution model of a mobile node, a more informed CAC decision can be made, which offers higher grade of service to the end applications.

II. WiMAX COMMUNICATION AT VEHICULAR SPEEDS AND THE CAC PROBLEM STATEMENT

The mobile WiMAX (802.16e) standard includes the air interfaces for fixed and mobile broadband wireless access. The standard contains technical specifications in relation to the convergence sublayer (CS), MAC layer, and physical (PHY) layer [8]. The theoretical capacity of the IEEE 802.16e is 70 Mbps over a 112.6 km range. This capacity however, is difficult to achieve in most practical cases and in practice, the IEEE 802.16e is capable of delivering up to 10 Mbps at around 10 km for the line-of-sight range. This throughput further decreases when the SS moves at vehicular speeds through different communication environments. As common in wireless communications, many objects in the environment surrounding a transmitter and receiver act as reflectors of the original radio signal, which create multiple paths that the original signal can traverse causing the receiver to experience the overlapping of multiple copies of the transmitted signal, each traversing a different path and having differences in attenuation, delay and phase shift while travelling from the source to the receiver. Such overlapping of signals cause interference either amplifying or attenuating the signal power received at the receiver known as the fading problem. Although orthogonal frequency division multiple access (OFDMA) in the 802.16e has the ability to utilize the guard channel to reduce the impact of intersymbol interference (ISI) caused by multipath transmissions, multiple access of users and multipath fading can still cause significant deterioration in network performances, especially when the end nodes move at vehicular speed. Fading problem causes error in bits received by the receiver and therefore, probability of bit error becomes higher at increasing speeds, limiting the usable throughput.

As discussed in the previous section, the WiMAX technology has been designed with QoS in mind and the CAC scheme is an important part of the QoS architecture that prevents over commitment of available resources. Let us consider a SS that is currently (at time t) moving at a speed of v_t . The maximum speed the SS can reach is v_{max} and there are n number of QoS sensitive connections currently being serviced by the BS, consuming a total of B_t bps of usable throughput. A new connection request has arrived with a demand of b bps. Without loss of generality, the CAC scheme can be considered as a mechanism that will accept the connection if and only if the following condition is satisfied:

$$C \geq b + B_t \quad (1)$$

The usable throughput capacity C varies with speeds and decreases sharply when the SSs start to move at high vehicular speeds. As the usable throughput decreases, dropping rate increases significantly, causing serious degradation of QoS. Existing CAC schemes do not consider this aspect of WiMAX communication while making a CAC decision. In this work, we have considered the impact of speed on usable throughput capacity and proposed a new CAC scheme that improves the dropping rate and grade of service.

III. PROPOSED CAC SOLUTION

The key idea behind the proposed scheme is to estimate the usable throughput in WiMAX communication as the SSs start to move at various speeds, and take this information into account while making a CAC decision. In our previous work [11, 13, 15], we showed that it is possible to derive a mathematical formulation to estimate the bit error rate in WiMAX communication at various vehicular speeds. In Section 3A, we reproduce on how to calculate the estimated usable throughput at various mobile terminal speeds. In Section 3B and 3C, we show how to make a CAC decision based on the estimated usable throughput computed taking the speed distribution model of a mobile node into account.

A. Throughput and mobile terminal's speed

Rayleigh fading [9][10] is known as an excellent model to represent the error in radio signal propagation caused by multipath fading. For a wireless communication channel that is characterized by the parameters: N be the number of OFDM sub carriers, f_m be is the Doppler frequency where $f_m = f_c(v/c)$, v be the speed of mobile nodes, c be the speed of light, f_c be the carrier frequency, T_s be the duration of each M -ary QAM symbol, E_s be the average symbol energy, E_b be the average energy per bit, N_o be the noise energy, γ_b be the received bit-energy-to-noise ratio, $\bar{\gamma}_b$ be the average received bit-energy-to-noise ratio, γ_s be the received symbol-energy-to-noise ratio, $\bar{\gamma}_s$ be the average received symbol-energy-to-noise ratio, $P_b(\gamma_b)$ be the probability of received bit error. Following the Rayleigh fading model [10], we can express the probability density function of received symbol energy to noise ratio as

$$p_{\gamma_s}(x) = \frac{1}{\bar{\gamma}_s} e^{-x/\bar{\gamma}_s}, x \geq 0 \quad (2)$$

and the average symbol error probability for a such channel can be expressed as

$$P_M = \int_0^{\infty} P_M(x) p_{\gamma_s}(x) dx \quad (3)$$

where the average received symbol-energy-to-noise-ratio is given by

$$\bar{\gamma}_s = \frac{1}{1 - \frac{1}{N^2} \left[N + 2 \sum_{i=1}^{N-1} (N-i) J_0(2\pi f_m T_s i) \right] + \frac{NT_s}{\left(\frac{E_s}{N_o} \right)}} \quad (4)$$

Now the average received bit-energy-to-noise ratio $\bar{\gamma}_b$ can be derived from the average received symbol-energy-to-noise ratio $\bar{\gamma}_s$ according to the following equation:

$$\bar{\gamma}_b = \frac{\bar{\gamma}_s}{\log_2 M} \quad (5)$$

where M is the number of symbols for M -ary QAM modulation scheme. Combining Eq. (4) and (5), we can express $\bar{\gamma}_b$ as:

$$\bar{\gamma}_b = \frac{1}{\log_2 M} \left[1 - \frac{1}{N^2} \left[N + 2 \sum_{i=1}^{N-1} (N-i) J_0(2\pi f_m T_s i) \right] + \frac{NT_s}{\log_2 M} \left(\frac{1}{\frac{E_b}{N_o}} \right) \right] \quad (6)$$

For a fixed channel with a known modulation scheme and unchanged values of N , NT_s plus relatively constant E_b/N_o over time, the main source of error for a mobile terminal is the velocity v that has direct impact on f_m , which in turn influences received symbol/bit energy to noise ratio. According to the

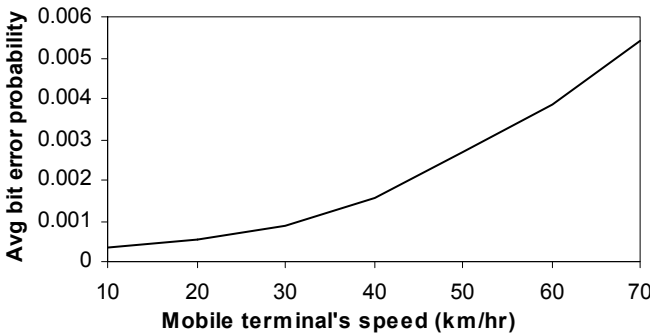


Figure 1: Average bit error probability at various mobile terminal's speed.

equation, higher will be the speed, lower will be the received symbol/bit energy to noise ratio. For OFDMA air interface, the main source of bit error is the inter-carrier interference instead of interference between the OFDMA users. Additive white Gaussian noise (AWGN) [10] is often used to successfully approximate the OFDMA inter-carrier interference. Taking AWGN into consideration, we can derive the bit error probability as

$$P_b(v) = Q(\sqrt{2\gamma_b(v)}) \quad (7)$$

where bit error probability P_b and symbol error probability P_M of OFDM are related to each other in the form of

$$P_b \approx \frac{P_M}{\log_2 M} \quad (8)$$

For $M=2$ or $M=4$, the average bit error probability is given as

$$P_b(v) = \frac{1}{2} \left[1 - \sqrt{\frac{\bar{\gamma}_b(v)}{1 + \bar{\gamma}_b(v)}} \right] \quad (9)$$

Bit error probability for higher order of M can also be obtained from:

$$P_b(v) \approx \frac{\int_0^{\infty} P_M(x) p_{\gamma_b(v)}(x) dx}{\log_2 M} \quad (10)$$

For a scenario where carrier frequency f_c is 2.6 Ghz, bandwidth is 12 MHz, number of sub carriers N equals 2048, symbol period equals 149.33s, modulation scheme is QPSK and E_b/N_o equals 5 dB, the above expressions lead to a relationship between the average bit error probability and mobile terminal's speed that can be depicted as shown in Fig. 1.

B. Impact of speed and CAC decision

For a mobile SS with a top speed (or a maximum allowed speed e.g., 110 km/hr in Australia) of v_{max} , it is possible to estimate the average bit error probability P_b at v_{max} from Fig. 1 or Eq. (9). For a m bit symbol, the relationship between average bit error probability and average symbol error probability P_s can be expressed as:

$$P_s(v_{max}) = 1 - (1 - P_b(v_{max}))^m \quad (11)$$

For a packet comprising T symbols, number of estimated corrupted symbol t can be computed as:

$$t(v_{max}) = T \times P_s(v_{max}) \quad (12)$$

Assuming reed-solomon (RS) code will be used for error recovery at the receiver end, the number of required parity symbols F can be given as:

$$F(v_{max}) = 2T \times P_s(v_{max}) \quad (13)$$

A data packet has overhead in the form of a header (h) and RS code (F), which will increase with higher bit error rate and vice versa. The overhead q per data bit for a data packet carrying K data bits (i.e., a packet can carry a maximum of K

data bits in a packet) for an end application can be expressed as:

$$q_{\max} = (h + mF(v_{\max})) / K \quad (14)$$

Since q per bit increases at higher vehicular speeds, this will reduce the usable transmission rate when the SS will reach its top speed. In order to address this problem while supporting a QoS sensitive connection that requires a usable data rate of b bps, WiMAX MAC needs to allocate a bandwidth in Hz for that connection, which is capable of delivering a total of b^* bps where

$$b^* = b + q_{\max} b \quad (15)$$

Here, b represents the bandwidth demand in bps for the end application and $q_{\max} b$ represents the overhead that is required to ensure that the usable data rate remains at b bps even when the SS reaches its top speed.

Assuming C being the channel's aggregate data transmission capacity when the SS is at stationary position, we propose to use a CAC scheme that will make a decision as following:

Accept a request if and only if:

$$C \geq b^* + \sum_i b_i \quad (16)$$

where b_i represents the bandwidth currently being used by the i -th QoS sensitive connection and b in bps is the bandwidth demand of the new call.

The CAC rule, as indicated in Eq. 16, may prove conservative and overcompensating at times as it always considers the top speed of the SS while computing the overhead and bandwidth requirement for a connection. This is likely to have an impact, particularly when a SS occasionally moves (i.e., city driving) at its top speed. In the following, we show that a probabilistic model can be developed and used for CAC scheme so that overcompensation can be avoided.

C. Speed distribution model and WiMAX CAC scheme

Researchers involved with transport research have long been conducting research to come up with a model that represents the free speed distribution of moving vehicles. Most of the studies available in literature so far suggest that the speed data of a moving vehicle on a highway follows the normal distribution [14]. Assuming μ being the mean speed of a moving vehicle and σ being the standard deviation, probability density function of a moving vehicle can be expressed as:

$$p_v(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (17)$$

For such a speed distribution model, the probability that the vehicle will be traveling at a speed greater than v_{th} can be given as:

$$p_v(x > v_{th}) = \int_{v_{th}}^{\infty} p(x) dx = Q\left(\frac{v_{th} - \mu}{\sigma}\right) \quad (18)$$

Now let us assume that the CAC scheme has received a connection request that requires b bps. As the speed of the SS will increase, overhead (in the form of RS code) to maintain b bps data rate, will increase as well. For the connection in consideration, the maximum overhead that the channel can withstand/support is $C - (b + \sum_i b_i)$. If the SS moves at a

speed that causes an overhead more than $C - (b + \sum_i b_i)$, it

will be necessary to drop some of the ongoing calls so that a data rate of b bps can still be maintained. In context of the incoming call, we define v_{th} as the maximum speed limit that the vehicle can reach before there is any threat to drop the call. The value of v_{th} can be derived from Eq. 9 or Fig. 1 once the maximum bit error probability $P_b(v_{th})$ that the channel can withstand can be computed. Based on Eqs (11)-(16), the maximum bit error probability $P_b(v_{th})$ that the channel can withstand, can be given as:

$$\begin{aligned} P_b(v_{th}) &= 1 - [1 - P_s(v_{th})]^{1/m} \\ &= 1 - \left[1 - \left[K \left\{ C - (b + \sum_i b_i) \right\} / 2Tmb + h / 2Tm \right]^{1/m} \right]^{1/m} \end{aligned} \quad (19)$$

Once v_{th} is computed, the call dropping probability P_{drop} can be computed from Eq. 17 as the probability of call dropping will be same as the probability of exceeding the safe speed limit. The revised CAC scheme then can be given as:

Accept a request if and only if:

$$C \geq b + \sum_i b_i \text{ and } Q\left(\frac{v_{th} - \mu}{\sigma}\right) \leq P_{drop} \quad (20)$$

where P_{drop} is the agreed/desired call dropping rate, decided based on the service level agreement and v_{th} is the safest speed limit, computed from Eqs. (19) and (9) for the call in consideration, that the channel can withstand before dropping some of the existing calls.

IV. SIMULATION RESULTS

The simulation was conducted in NS2 for an Internet communication service on a public train as shown in Fig. 2.

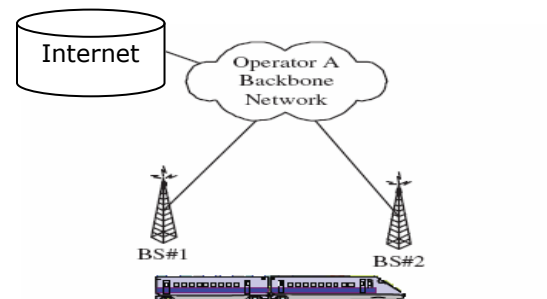


Figure 2: Simulation scenario.

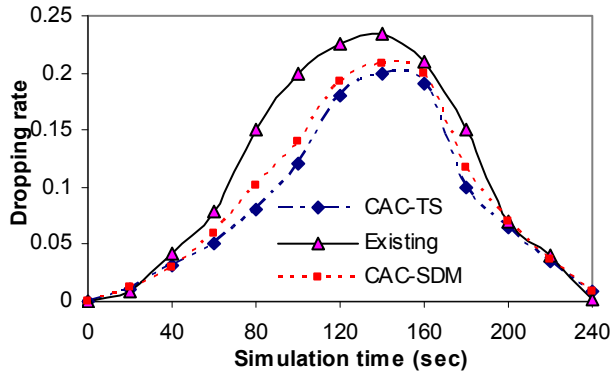


Figure 3: Comparison of call dropping rate in the proposed and standard CAC schemes.

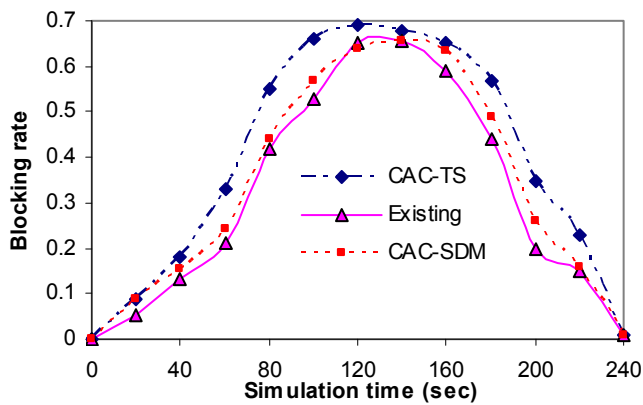


Figure 4: Comparison of call blocking rate in the proposed and standard CAC schemes.

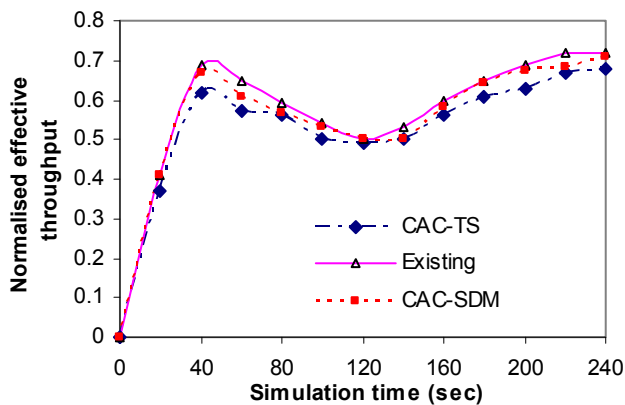


Figure 5: Comparison of bandwidth utilization in the proposed and standard CAC schemes.

The maximum data rate capacity of the WiMAX channel was 20 Mbps. The carrier frequency was 2.6 GHz with a bandwidth of 12 MHz, number of sub-carriers was 2048 and the modulation style was QPSK. Two groups of traffic were considered: first group required QoS guarantee and the second group was for best effort applications. Bandwidth demand for

each application was uniformly distributed in the range of 128 to 512 Kbps. Arrival of connection request was assumed to follow the Poission distribution with a mean interval of 250ms. Lifetime of each connection was exponentially distributed with a mean of 60s. For the simulation scenario, the train (SS) moves from a stationary position and increases its speed, reaching a top speed of 70km/hr at 120sec time. The train starts to slow down at 160 sec and finally stops at the next station at 240sec. The mean speed was considered to be 50 km/hr with a standard deviation of 0.0003. We monitored the connection dropping rate, blocking rate and overall utilization of the channel as the train moves at various speeds.

Figure 3 shows the comparison of connection dropping rate in the proposed and existing CAC schemes. The CAC schemes as proposed in Section 3.2 and 3.3 are denoted as CAC-TS (CAC for Top Speed movement) and CAC-SDM (CAC with Speed Distribution Model), respectively. The existing CAC scheme (i.e., CAC in [5]) considers the channel condition at the immediate moment when a new QoS demanding connection arrives, and computes the available resources accordingly. It does not consider the fact that the channel condition might deteriorate significantly when the SS will reach at its top speed. This is why when the train gradually increases its speed, more calls that were previously admitted based on past channel state information at lower speeds, are dropped in the existing CAC scheme. The CAC-TS and CAC-SDM scheme takes the future channel condition into account while admitting the QoS sensitive applications. The improvement achieved in the proposed schemes is significant (about 5%) at around 120s time when the train reaches its top speed.

Figure 4 shows the call blocking rate in the proposed and existing scheme. Since the CAC-TS scheme follows a conservative approach during the CAC decision making process, it blocks more calls compared to the existing and CAC-SDM scheme. This is why the blocking rate in the CAC-TS scheme is the highest. The CAC-SDM scheme demonstrates its merits here as it blocks calls decisively instead of always using the top speed information. The CAC-SDM scheme blocks less number of calls compared to the CAC-TS scheme. The CAC-SDM scheme however, blocks more calls than the existing scheme. This however, does not limit the merit of the proposed schemes as, for a network that is designed with QoS in mind, blocking is always considered a preferred option over admitting a connection first and then dropping it. Figure 5 shows the utilisation of the channel computed as the ratio of actual transmitted throughput to the channel capacity. As evident in the figure, the proposed schemes perform comparably against the existing scheme even though it blocks more call compared to the existing scheme. This is because the proposed scheme prefers to block those connections that demand higher amount of bandwidth. As a result, calls that demand lower amount of bandwidth get more chance to access the channel, keeping the channel busy. The other reason behind a good utilisation is that best effort traffic continues to utilise the bandwidth left unused in the system, which ultimately contributes to a better channel utilisation.

Effective utilisation as a whole drops significantly at high speeds when the bit error rate increases.

V. CONCLUSION

WiMAX is equipped with mechanisms to deliver guaranteed QoS, and CAC is an important part of WiMAX design that contributes to improved QoS. Existing CAC schemes are more suitable for fixed WiMAX as they do not consider the dynamic channel condition caused by mobility at high vehicular speed. In this paper, we proposed a CAC scheme, the first of its kind, that estimates the usable channel capacity for various vehicular speeds and use this information while making a CAC decision. The benefit is clearly evident in the simulation results that confirm that dropping rate improves significantly in the proposed CAC schemes. The proposed schemes perform comparably in terms of call blocking rate and channel utilization.

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