CALL ADMISSION CONTROL IN MOBILE WIRELESS

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Abstract

Some problems related to wireless network access are discussed in the article. Special attention is paid to Medium Access Control and Call Admission Control. Both have direct impact on communication link accession. While the first one dictates how to, the second one decides who can access the link. The problems with wireless medium access are mentioned and requirements on MAC protocols are named. Also need for CAC algorithms is illustrated and simple functional example is proposed. Finally, the reasons for future enhancements are shortly discovered.

Keywords

Call Admission Control, Medium Access Control, Wireless Mobile Communications

1. Introduction

In last years, communications changed significantly. Advances in wide scale of technologies enable portable computers to be equipped with wireless interfaces, allowing networked communication and mobility, anymore. Whereas today's notebooks and personal digital assistants are self-existent devices, networked mobile computers of the future seem to be a part of greater computing infrastructure.

Two trends – mobile computing and multimedia applications – will lead into a new application domain and market in the future. Internet access, client-server applications with remote servers, video-on-demand and interactive multimedia are just a few examples of new services, in addition to traditional voice-telephony. Wireless-based access technologies offer an attractive alternative to classical wireline loops and analogue modem-based access.

Combination of existing applications with incoming ones (some of them are still undefined) requires a technology able to meet various access requirements, such as quality of service (QoS) and available bandwidth. This need implies access scenarios to cover the overall transport of these applications. There is evidence of trend toward transport and access integrating technologies [1].

It is estimated that 99.4% of corporate U.S. locations require bandwidth from 9.6 kb/s up to 1.5 Mb/s to support current low-speed applications. With oncoming multimedia and telecommunication applications, such as video-conferencing and LAN interconnects, these bandwidth requirements will increase at a rate of 26% per year [2].

The new services will have a wide variety of transmission rates and delay tolerances combined with varying degrees of burstness (ratio of peak to average transmission rate). Since some of these services depend on bandwidth guarantees, the network should employ some mechanisms to prevent network links from becoming overloaded. This includes making intelligent decisions about whether to accept new call or not, and if appropriate, when to schedule it and how to route it [3]. In addition, future personal mobile devices will have limited energy resources, will handle diverse data types and will operate in environments, that are unplanned, insecure and time varying. [4].

One from challenges mentioned above – Medium Access Control (MAC) – will be filling of following paragraphs. Special attention will be imposed to Call Admission Control (CAC) – the instrument for acceptation or rejecting of new call.

2. Medium Access Control

Multimedia applications will be dominant part of future network applications. Successful launching of them invokes support of predefined QoS. The QoS guidelines for multimedia applications were established by Multimedia Communication Forum (MMCF) – see Tab. 1 [11]. With goal to match these criteria, Asynchronous Transfer Mode (ATM) was developed. ATM provides a framework for present Broadband Integrated Services Digital Network (B-ISDN), which represents hopeful aspirant for global wired-loop communication network.

It is natural that future network user will expect the same QoS guarantees while using either of wired or wireless access method. Hence, many of ATM techniques are employed also in wireless technology bringing new paradigm – Wireless ATM (W-ATM).

QoS parameter	QoS Class 1	QoS Class 2	QoS Class3
Audio Transfer Delay with Echo Control	< 400 ms	< 400 ms	< 150 ms
Audio Frequency Range	≥ 0.3 – 3.4 kHz	≥ 0.3 – 3.4 kHz	≥ 0.05 – 6.8 kHz
Audio Level (Typical)	-20 dBm0	-20 dBm0	-20 dBm0
Audio Error Free Interval	> 5 min	> 15 min	> 30 min
Video Transfer Delay	< 10 s (still image only)	< 600 ms	< 250 ms
Video/Audio Differential Delay	N/A	> -400 and < 200 ms	> -150 and < 100 ms
Video Frame Rate	N/A	> 5 frames/s	> 25 frames/s
Video Resolution	N/A	≥ 176 x 144	≥ 352 x 288
Video Error Free Interval	N/A	> 15 min	> 30 min
Data Rate	≥ 5 kbps	≥ 50 kbps	≥ 500 kbps

Tab. 1 MMCF QoS class guideline.

2.1 Wireless Medium Issues

ATM was designed to use highly reliable communication medium – the optical fibre. With this medium very low error rate, high reliability, sufficient bandwidth and constant characteristics are achieved due to its nature. But in radio link environment these parameters are not enough guaranteed and are greatly times varying [5].

Standard ATM transmission cell cannot be transmitted directly through the radio link because of high cell-loss probability and considerable transmission delay. There is necessity to build up mechanism to integrate radio link into ATM network without intervention into existing ATM Adaptation Layer (AAL) protocols. The solution is to extend standard ATM cell by subsidiary header and trailer (may be compressed to reduce cell length increasing). Wireless extension entities are shown on Fig. 1.

W-PHY – **Wireless Physical Sublayer** provides high-speed transmission through the radio link.

MAC – Medium Access Control Sublayer determines how many and which of mobile terminals can send data to base station.

DLC – Data Link Control Sublayer provides error-protection on data being sent and error-recovery on received data.

Wireless Control Sublayer enables to administrate all new sublayers and their functionality.

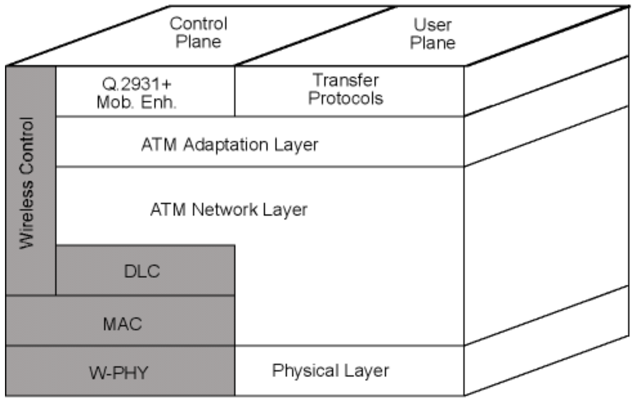

Fig. 1. W-ATM reference model used for 3G wireless.

W-PHY, DLC and MAC sublayers are usually entitled as Radio Access Layer (RAL). Since CAC algorithms as a part of MAC protocol are the basis of new functionality, in following MAC mission and general requirements defined for MAC protocols will be described.

2.2 What Does MAC Do

In general, MAC sublayer determines which access method will be used for communication. In the other words, it decides, how to communicate through the radio link, i.e. which kind of duplex and which multiply access will be used. Since employed protocol and duplex greatly impact performance of entire wireless network, complexity of used equipments and total system capability, it is necessary to dedicate heavy attention to the choice of the best of them. By now, there are several multiply access types and duplex classes commonly used in mobile wireless. A short overview is proposed in later subsection.

The other MAC task is supervisory over the newly incoming and existing calls. This is the role of CAC algorithms, discussed in special section.

Generally speaking, there is two-way data exchange in any communication network. There is data exchange between the end-point device and the network on one side, and data exchange between the network and the end-point device on the other side. Situation is the same in mobile network. The role of the end-point device performs mobile terminal and network entry point is represented by the base station. The most uncertain part of transmission chain is the radio link, or radio channel. Just this is the scope of MAC, in order to provide concurrent communication of more users. MAC arrangement into Open System Interconnection Reference Model (OSI RM) is shown on Fig. 2. It is depicted using IEEE 802.11 standard for Wireless LAN (W-LAN).

Data transmission between mobile terminal and base station is often denoted as

- Up Link – from mobile terminal to base station,
- Down Link – from base station to mobile terminal.

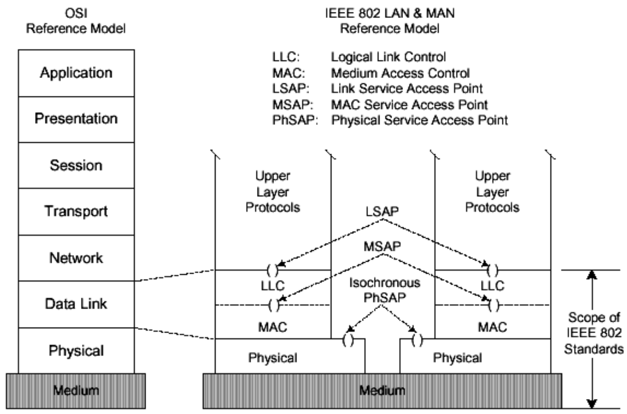

Fig. 2 MAC arrangement into OSI reference model.

MAC protocol is usually used in case of Up-Link, where concurrent access of more users to single transmission medium (radio channel) is required. It must solve rather complicated problem, because unknown operational characteristics of individual users (call generation, duration, etc.) prohibit traffic scheduling. Down-Link is controlled from the base station and its management is not so complicated.

2.3 QoS Parameters

Whole MAC's effort has simple aim – to satisfy user QoS requirements. It is time to clarify what the QoS means.

There are two views on QoS requirements:

- QoS requirements at cell level
- QoS requirements at call level

QoS requirements at call level are:

- audio and video synchronization
- packet delay
- error rate
- packet loss

QoS requirements at cell level are:

- new call blocking probability
- handoff blocking probability

To differentiate QoS requirements at call level from those ones at cell level, the QoS requirements at cell level are often labelled as Grade of Service (GoS). As a part of MAC, the CAC module is liable for GoS requirements satisfaction.

2.4 Protocols and Duplex Classes

Multiple access methods can be differentiated into three classes:

- **Frequency Division Multiple Access (FDMA):** frequency spectrum is divided among several users and every user can communicate with the base station on its own frequency. This is the most commonly used method in the 1-st generation cell systems.
- **Time Division Multiple Access (TDMA):** every radio channel is divided into several time slots, which are periodically repeated. Different users can communicate in their own time slots. TDMA is usually further subdivided according to used duplex scheme to **TDMA with Frequency Division Duplex (TDMA-FDD)** and **TDMA with Time Division Duplex (TDMA-TDD).**
- **Code Division Multiple Access (CDMA):** every user has its own code word for spectrum spreading over the whole system bandwidth. The 2-nd and 3-rd generation wireless use this method.

Multiple access methods can be differentiated also according to bandwidth allocation mechanism:

- **Methods with Fixed Bandwidth Allocation:** constantly reserve one subchannel with fixed bandwidth, for whole duration of every call. They work effective with Constant Bit Rate (CBR) services, but are unworthy with Variable Bit Rate (VBR) services. Typical representatives are based on TDMA, FDMA or CDMA.
- **Methods with Random Bandwidth Allocation:** enable users to transmit everytime they need, if collision occurrence, packets are transmitted once again with random delay to prevent repeated collision. These methods are effective with VBR and bursty operation, but are unstable with heavy load and unsuitable for statistic multiplexing commonly used in fixed networks. Typical representative is ALOHA.
- **Methods with Allocation On Request:** users request bandwidth depending on their needs, they declare expected operational characteristics to base station. There are two phases – reservation and transmission. These methods are usually complicated, but robust under greatly varying load conditions.

2.5 Requirements on MAC Protocols

Basic requirements were summarized in IEEE 802.11 (implicitly or explicitly) and were commonly accepted in wireless community [9] [10]. Here they are:

1) Throughput
2) Delay
3) Ability to serve voice, video and data
4) Packet order conservation
5) Roaming support
6) Priority support
7) Non-symmetrical link support
8) Battery energy consumption minimization
9) Fair contention based decision algorithm
10) Ability to work in wide-band systems
11) Transparency against various physical layers
12) Limitation of unauthorized access impact to throughput
13) Single/multi-point transmission support

14) Critical delay limits with large area coverage
15) Reflection proof
16) Limited complexity

The most important are delay, throughput and priority support requirements. The last one can be used to advancing some service type (CBR, VBR, etc…) dependently on operational needs, or to preferring calls switched from neighboring cells (handover, handoff) at the expense of calls incoming from local cell.

MAC protocol is usually segmented into:

- Supervisory MAC (S-MAC)
- Core MAC (C-MAC)

S-MAC provides control functionality over the MAC itself. It handles Up-Link and Down-Link channel scheduling, builds QoS parameters table and deals with call admission control. C-MAC represents core of protocol and works as interface between DLC and W-PHY sublayers. It multiplexes and demultiplexes channel packets depending on channel scheduling table.

MAC disposes with rich functionality to adapt data to wireless link transmission, to catch various link conditions, and to fill user QoS requirements. It employees number of sundry algorithms (packet scheduling, access method selection, new call acceptation and many others) while trying to enable communication of as many users with as QoS guarantees and as little energy consumption as possible. The most important algorithm is the one serving calls incoming from adjacent cells and accepting or rejecting new call requests – CAC.

3. Call Admission Control

Wireless ATM system was nominated for next generation broadband and multimedia personal communication. W-ATM based network is expected to provide a seamless interconnection between a mobile terminal and wired ATM network, so that multimedia applications supporting voice, video and data can be implemented at mobile terminal.

Various service classes were defined in order to support multimedia applications. They include:

- **Constant Bit Rate (CBR)** – used mostly to abide backward compatibility. Constant transmission rate is generated e.g. using PCM coding in voice telephony. Present coding techniques trend to variable bit rates using instead of CBR.
- **Variable Bit Rate (VBR) –** about 60% of normal telephony conversation duration the speaker keeps silence. This silent passage can be coded into markedly smaller data package than spoken words. It enables to use network resources more effectively. Depending on real-time transmission necessity, two VBR classes are defined – **realtime - VBR (rt-VBR)** and **non-realtime – VBR (nrt-VBR)**.
- **Available Bit Rate (ABR)** - used for non-realtime produced data. Transmission uses bandwidth being momentary available.
- **Unspecified Bit Rate (UBR) –** also used for non-realtime produced data. No bandwidth specification is made at connection establishing. This service class is often minimally supported by networks.

One can expect, that future mobile network will support all of them, as well, it will enable user being moving during communication without QoS degradation or, in the worst case, connection loss. Here the problem comes – how to manage communication channel to provide guaranteed bit rate and to eliminate connection losses.

With aim to satisfy these contradictory tasks the pico-cellular structure philosophy is widely used in new generation wireless [8]. New pico-cells are very small, with only few meters of diameter. Individual frequencies can be used more frequently so higher bandwidth in the same area is available. However, handoffs also become more frequent, what is the cause that connection loss probability rises up. The problem how to manage existing and new calls becomes more sharp.

Fundamentals of CAC algorithms are often illustrated using following example from TDMA network [6][7]. CAC algorithm controls acceptation of new calls and reservation of specific number of time slots for handoff calls. If there would been reserved too many slots for new calls from local cell, there would remain few slots for handoff calls from adjacent cells. Thereafter, with rising demand for handoff calls there also rises demand for sufficient amount of free time slots. But network with only few reserved slots cannot achieve requested QoS for such many calls. It results to losing of existing calls. In reversal case, if there would been reserved too much slots for handoff calls, there, however, would be nought handoff blocking, but new call blocking probability would be too high. With small amount of handoff calls only small part of available bandwidth would be used for communication. It results into non-effective network capability utilization. Notwithstanding, if there would been specified reasonable, but fixed value for reserved slots quantity for both, new and handoff calls, it still tends to inadequate network resources employment due to network load differences in both, time and space. Network load varies with daily hour – it is different in daytime and in the night. Also, it differentiates in rural and urban area. This is the reason for employing CAC algorithm to dynamically regulate slots reservation threshold dependently on an actual situation in local cell and neighboring cells.

3.1 Threshold Oriented CAC Algorithm for Wireless Networks

From the user view, unexpected call drop-out is more annoying than new call blocking. From those implies higher acceptation priority for handoff call in respect to new one. Probability of call drop-out must be lower than probability of new call rejecting. Handoff call is accepted every time free slots exist, but new call can be accepted just when total number of occupied slots after call acceptation is lower than CAC threshold for given service class. For simplicity, CBR service can be considered [12].

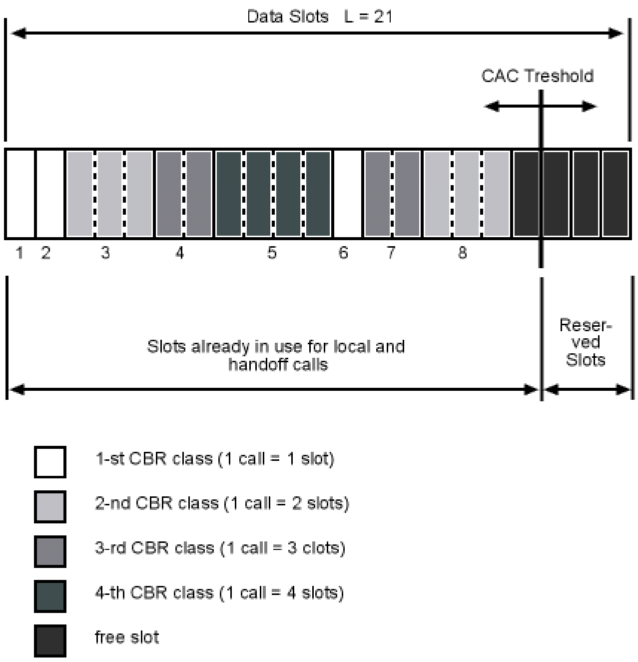

Fig. 3 Function principle of threshold oriented CAC algorithm.

Using dynamic threshold, network monitoring becomes necessary. It collects statistical data from local cell particularly for every service class. Average call duration, number of new calls per hour and number of handover calls per hour are the scope of interest. This data are completed with information about actual network state and altogether enter algorithm that computes optimal CAC threshold value. If some datum takes a change, new threshold must be evaluated. Now it will be detailed how it works.

Consider, that every frame has a number of L slots and number of slots required for i-th ($i = 1,2,\dots,K$) CBR class is b_i. CAC threshold for i-th CBR class is denoted by N_i. Parameter K indicates number of CBR classes in given wireless network.

Example of network load is depicted on Fig. 3. There, the number of slots $L = 21$ and the number of CBR classes $K = 4$ are considered. The first class needs for communication $b_1 = 1$ slot, the second one $b_2 = 2$ slots, the third one $b_3 = 3$ slots and finally the fourth class needs $b_4 = 4$ time slots. There are 3 calls in the first class, 2 calls in the second class, 2 calls in the third class and 1 call in the fourth CBR class. The CAC threshold is considered being the same for all classes, its value is $N_1 = N_2 = N_3 = N_4 = 15$ time slots.

Two alternatives can occur:

1) New call of i-th CBR class arrival case

Let the number of i-th CBR class calls already accepted by network is denoted by m_i. Then, new call is accepted just if following equation is met:

$$N_i \geq \sum_{j=1}^{K} m_j b_j + b_i \tag{1}$$

where b_i denotes the number of time slots required by incoming call of the i-th class, b_j denotes the number of time slots required by call of the j-th class, m_j denotes the number of the j-th class calls already accepted by network, N_i denotes CAC threshold for the i-th class, K denotes the number of service classes in the network.

It means: if the sum of all time slots already occupied plus new call requirement is less than or equal to CAC threshold for given class, new call is accepted. Otherwise, it is rejected.

2) Call of i-th CBR class handoff case

The condition to accept handoff call seems like follows:

$$L \geq \sum_{j=1}^{K} m_j b_j + b_i \tag{2}$$

where b_i denotes the number of time slots required by handoff call of the i-th class, b_j denotes the number of time slots required by call of the j-th class, m_j denotes the number of the j-th class calls already accepted by network, K denotes the number of service classes in network, L denotes the total number of slots in the system.

It means: if the sum of free slots is greater than or equal to the number of slots required by handoff call, the call is accepted. Otherwise, the call is dropped-out.

3.2 A Markov Decision Approach

A simple CAC algorithm was described in former paragraph. Now, the basic approach to dynamic CAC threshold estimation will be introduced [7].

It is commonly known that user arrivals are random. Therefore, arrival characteristics (average number of incoming users per time unit, average time of user abidance in system, etc.) are interesting. Typical phenomenon in communication network is that if there are none free links, the user is omitted; i.e. creating of users queue is not assumed. For simplicity, just one user-type is considered, e.g. just one CBR class. Bulk service system labeled as *M/M/n* with zero queue length is suitable for network with such characteristics.

This system type is characterized as follows: users come into system in single, independently of each other and independently of maintenance behavior. It is assumed, that new call arrivals match a Poisson process with mean λ and channel holding times meet exponential distribution with mean $1/\mu$. There are n independent and equivalent service units in disposal to incoming users. System does not assume creating of waiting users queue, therefore if the system is overloaded, the user is omitted. The number of system states is limited by number of service units. Example of Markov chain describing such a system with L service units is depicted in Fig. 4.

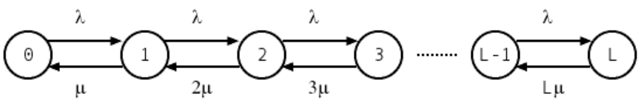

Fig. 4. Markov chain example.

λ is a parameter of Poisson process and represents intensity in which new users come into system; μ is a parameter of exponential law and characterizes user service duration.

There is over-elaborated theory how to solve Markov decision problem. It is not the aim of this article to concern about stochastic, so being very concise: Markov chain is described by system of probability equations. Poisson process is homogeneous Markov process that can be solved using system of Kolmogor differential equations. Its solution represents steady-state probability vector, which enables to derive probability of new call blocking and/or probability of handoff call drop-out.

One would say it is lovely simple. But reality is rather complicated. Follow the example.

Consider very simple network. Its services come under two CBR classes, i.e. $K = 2$. There are $L = 6$ time slots per frame. CaC thresholds are the same for both classes and are equal to $N_1 = N_2 = 4$. Time slots requirements for individual classes are $b_1 = 1$ and $b_2 = 2$. The numbers of calls per individual classes are denoted by m_1 and m_2. Fig. 5 shows Markov model of this simple network. Every circle represents one system steady state. The numbers in the circles are $[m_1, m_2]$. The steady state probability $\pi(m_1, m_2)$ will be the solution of Kolmogor equations system.

It is evident that this model is rather more complicated than that one inn Fig. 4. The model complexity grows up with the number of time slots available and, in addition, depends on time slots requirements for individual classes. E.g. adding the 7-th time slot into frame considered above will cause 4 new steady states – *[1,3], [3,2], [5,1]* and *[7,0]*. It is simple to count up how many new steady states will be induced by adding further time slots.

Situation becomes even more complicated by adding new service class. The model will attach K-th dimension. E.g. Fig. 5 shows 2D model for $K = 2$, but there would be 3D model for $K = 3$. Those equipped with good fantasy can try to imagine the model for arbitrary number of service classes. And those – the better, can try to incorporate VBR, ABR and UBR services. Is it difficult? Needless to say, it really is. And what is more, it is difficult not just to imagine, but also to compute and, in consecutive, to make responsible decisions. Therefore, not a little labor is dedicated after simplified models. Various techniques, such as neural networks, fuzzy logic, local policies and others are employed in the way to reduce computational complexity, to minimize signaling necessity, to make decision algorithm robust under massive load fluctuations and to manage network resources as effectively as possible.

4. Conclusions

Unprecedented progress in variety technologies reflects in new conveniences of usual life. It was as if yesterday, when A.G. Bell said his legendary words starting new epoch of interpersonal communication. Nowadays communication devices enable us to connect with anybody, anytime, anywhere. The future ones, apparently, add "with anything". Modern data networks are everywhere around us. Human need to communicate with/through this networks is still much more intensive day after day. This need turns on new problems having to be solved. Some of them related to wireless network access were discussed in former paragraphs. Special attention was laid to Medium Access Control and Call Admission Control. Both have direct impact on communication link accession. While the second one decides who can access the link, the first one dictates how. The problems with wireless medium access were mentioned and requirements on MAC protocols were named. Also need for CAC algorithms was illustrated and simple functional example was proposed. Finally, the reasons for future enhancements were discovered.

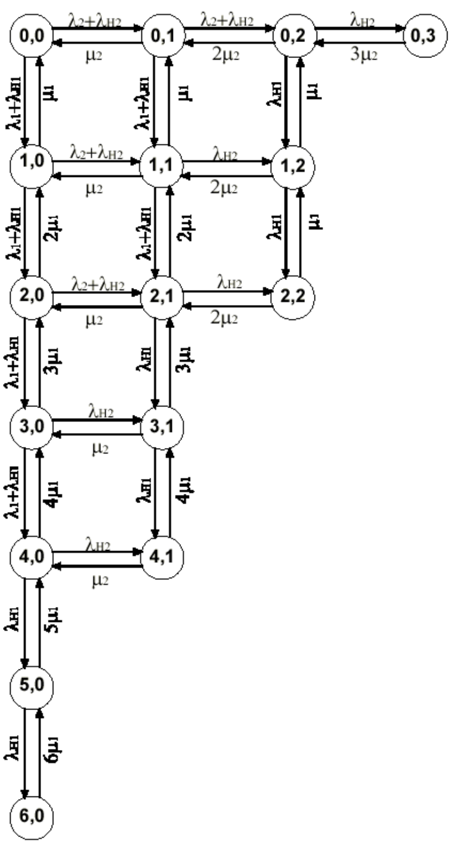

Fig. 5. Markov model example.

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