13. CHANNEL ALLOCATION

13.1. Introduction

When we discussed the *properties of information sources* in the previous chapters, we also determined the bandwidth required to transmit the information through a telecommunication channel. We know that for *analog sources*, the *highest spectral component* determines the frequency range occupied in the *baseband* while different *modulations* used for transposition of the signal spectra can significantly extend this range (e.g. AM-DSB requires twice as large bandwidth as that of the baseband and FM may use many times as much). For *digital* sources, the required bandwidth is the function of the bitrate, the spectrum-shaping coding and digital modulation methods. Efficiency of a given method is usually measured on the base *of unity bandwidth bit rate* (bit/s/Hz). *Typical values* are between 0.5 (for simple methods) and 5 (for complex, multi-level modulation procedures).

Earlier we have seen that because of physical reasons the frequency range of *wirebound* communications is limited in frequency. In *radio systems*, important legal regulations play also role beside the technical aspects. The bandwidth of *optical cables* is by many orders higher than that of the first two. Nevertheless, bandwidth or transfer capacity of telecommunication channel is generally much greater than the bandwidth required by the individual source signals. There are many cases when signals of several sources of information are to be transmitted together through a common channel. Methods used for solving problems of this kind are called multiplexing procedures.

13.2. Frequency and Time Division Multiplexing

Common channel can generally be divided in the *frequency* or in the *time* domain. (There is also a third method, called *code division* which will be discussed latter.) Frequency division multiplexing is abbreviated as FDM, similarly the short for time division multiplexing is TDM.

Let us overview these techniques on simple but frequently used procedures applied in *speech transmission*. When using FDM, baseband spectra of different speech signals are shifted to a higher frequency by single side AM-modulation and placed side by side to a common range. Details of such an FDM procedure for a base group containing 12 voice-grade channels is shown in Fig. 13.1.a) shows the baseband of the analog speech signal. Fig. 13.1.b) shows the symbolic notation of a standardized telephone voice-grade channel limited to the frequency range from 300 Hz to 3400 Hz. Ramp-shaped notation of the spectrum shown in the figure has nothing to do with its actual shape, it might just as well be represented by a rectangle, however this notation is well suitable to show how the spectrum position varies in consequence of different frequency transpositions (modulations). Fig. 13.1.c) shows the spectrum allocation of 12 channels in the 60 ... 108 kHz range.

FDM signal is composed according to the block diagram of Fig. 13.2.a). Each pair of multiplier and filter shifts one of the channels up to the appointed band. For instance, 60 kHz sinewave carrier $c_1(t)$ of the Channel 1 is cut off by a lowpass filter together with the lower sideband of the AM-DSB signal appearing at the multiplier output. Decomposition of the

FDM signal is shown on Fig. 13.2.b). Each input filter selects one channel which is 'shifted back' by a multiplier and a lowpass filter to the baseband.

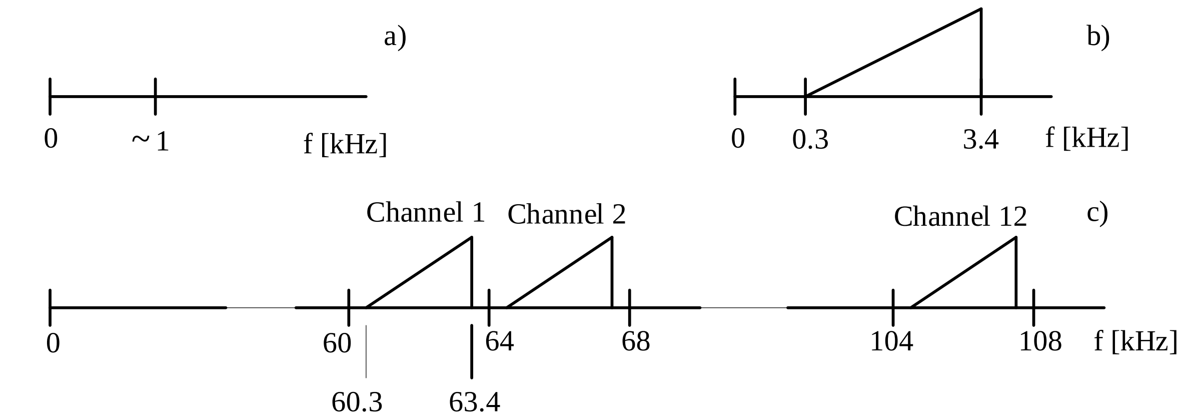

Fig. 13.1 Frequency Division Multiplexing of Voice Channels

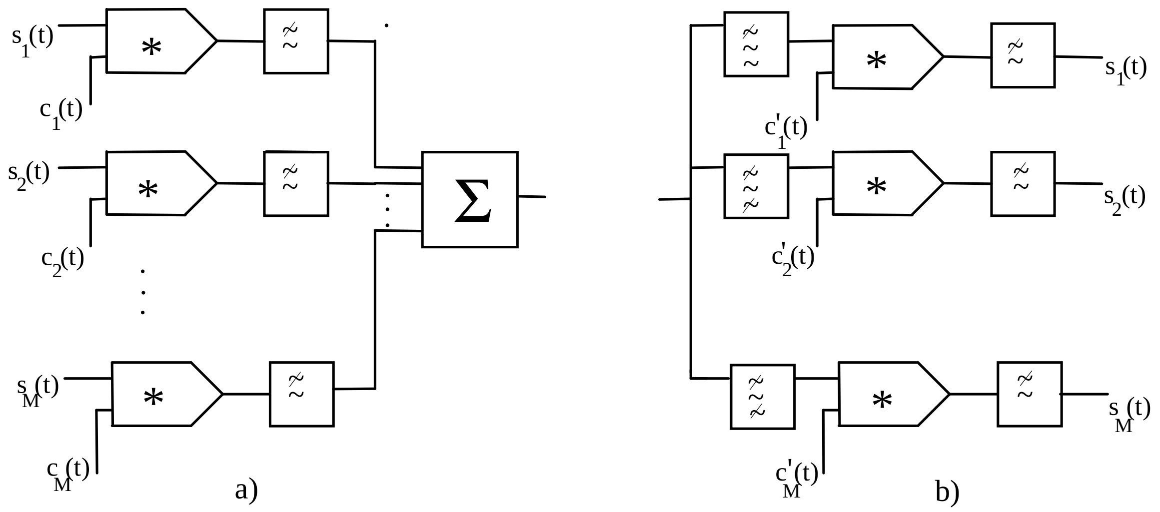

Fig. 13.2 FDM Signal Multiplexing and Demultiplexing

In the case of time division multiplexing we make use of the fact that the data rate can be much greater in the channel that the data rate of a digitized speech signal. Remember that telecommunication standards fixed 8 kHz as sampling frequency and 8 bit resolution for each sample, i.e. source data rate is 64 kbit/s. If 32 such sources are put together as it is done in primary data rate TDM generally used in telecommunication networks, the resulting data rate is 2048 kbit/s.

Summing up, frequency and time division multiplexing methods are used if more source signals are simultaneously present at the same point of a telecommunication system and they are collected to form a single FDM or TDM signal to be transmitted in one common broadband channel. However, the multiplexing of a common channel is needed also in cases when the source signals are not available at the same point (at the multiplex input). Methods described above can be used even in this case and they are denoted as FDMA and TDMA (Frequency-Division Multiple Access/Time-Division Multiple Access).

The practical use of the FDMA is limited since the division of a broadband channel into narrow subchannels -especially in radio systems- is not always possible because of legal and technical reasons and the application of individual narrowband transmitters and receivers can be expensive.

In TDMA, each individual station uses the same broadband channel but only in the time slot allocated for the station. If there is no information to be transmitted, the slot remains empty. If there is more information than what can be transmitted in a single time slot then the excess can be transmitted only in the following slot(s). Time division control may be centralized or distributed.

13.3. Code Division

Code-Division Multiple Access (CDMA) or Spread Spectrum Multiple Access (SSMA) is based on a special modulation technique called spectrum spreading. In the one of the main versions of the *spectrum spreading* technique, a transmitter-receiver pair uses a specific l bit long binary codeword and its inverse to represent "0"-s and "1"-s of the binary source (l is typically 16, 32 or 64). This procedure is called direct sequence spread spectrum.

In another main version called *frequency hopping* spread spectrum, sine-bursts of different frequencies are selected from a given set and inserted into the time-slots accordingly to a special code series. (The frequency hopping can take place slowly, i.e. the same frequency is transmitted during more time-slots or quickly, i.e. the frequency changes several times in one time-slot.)

In both cases, bandwidth of the modulated signal is significantly spread over a wider spectrum so that the transmitted power is spread to the same extent. Originally, spread spectrum modulation was developed for the protection of telecommunication systems against noise, since the signal spread over a wide frequency range cannot be disturbed by a signal with power concentrated into a narrower band or very high power would be required for the efficient disturbance.

As the basic principle of the spread spectrum multiple access, different code-series are assigned to different sources so that they can operate in the same frequency range using either the direct-sequence or the frequency hopping method. If the codeword length is l, 2^l different codewords can theoretically be assigned to, practically much less codewords are used (only those which can be "well distinguished", see chapter 7.)

So the spread spectrum technique can be used for multiplexing and for multiple access as well. As a characteristic example of CDMA, let us mention the part of Radio LAN-s (Local Area Network). Here, spectral density of the relatively wideband signal is kept at a low value so that several systems spread over a greater area can operate in the same frequency band without disturbing each other.

Let us go back now to the time division multiple access to discuss some of the efficient channel allocation techniques based on the TDMA methods.

13.4. Dynamic Channel Allocation. Polling Methods.

An obvious drawback of the so called *static TDMA* methods discussed above is that the time slot assigned to one station (user) is occupied even if the user is idle. Assuming that it is possible to exchange a message about the user's status between the TDMA system controller and the user, the time slot of the quiescent user can be used by the next user etc. Such a questioning of the user is called *polling* and time gained in this way is shortened by the time needed for the exchange of message.

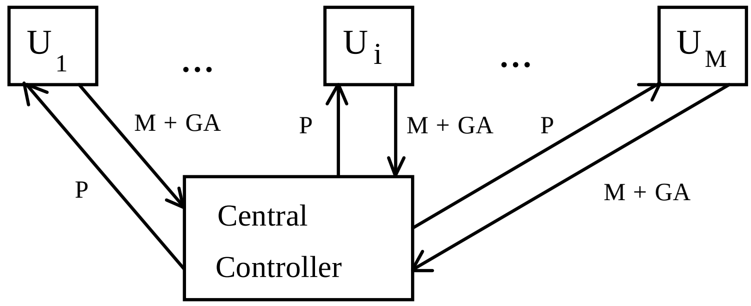

Fig. 13.3. Roll-Call Polling

One possible arrangement for polling is shown in Fig. 13.3. If the control messages P (poll) and GA (go ahead) are short in comparison to the useful message (M) and the propagation times between the central controller and the stations are also short, this system called "roll-call polling" works well. If the propagation time is not negligible, it is more advantageous to use the so-called "hub-polling" shown in Fig. 13.4. Here the time lost by the propagation can be much smaller since the right for go-ahead is passed directly from station to station.

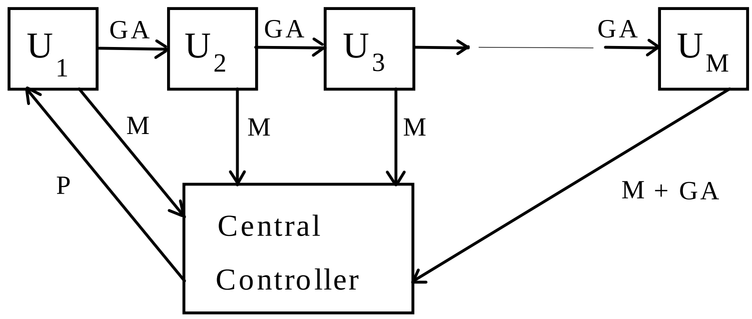

Fig. 13.4 Hub Polling

Polling methods are widely used in telecommunication systems. In a terminal network which is the oldest and most known such an application, local or remote terminals are connected to a controller which polls the terminals and passes the terminal messages towards a central equipment. Polling is also used in local area networks where this type of access is called *token-protocol.* 'Token' is the term used for short control messages the stations are passing to hand over the right of transmission. Central controller in not used in such a system, the stations fix up specific rules on the base of distributed algorithms, e.g. who has the token first or who starts when the token is 'lost' (faulty). Token is the principle of bus and ring local networks which will be discussed later.

Procedures discussed so far (FDMA, TDMA, CDMA, polling) belong to *scheduled* access methods. There is another group of so called *random* access procedures, although the term *free* access would be more adequate to express the principle of the method which will be discussed in the following.

13.5. Random Access Time Division Procedures

The principle of the random access based on the observation that the activity of the majority of the users is discontinuous, i.e. the duty cycle of their operations is small. The term 'duty cycle' has been borrowed from electronics to illustrate that the users actually engage the communication channel just for a small fraction of time while the majority of time is spent on the preparation of the messages. As an example, let us see the *dialog management* of an interactive terminal using 1200 bit/s (relatively low) data rate. Suppose the length of the message to be one row of text, program or any other data, the time needed for the transmission of the message is about 0.5 s while its preparation (typing in, checking, etc.) takes about 0.5-1 min., thus the duty cycle is in the order of 10^{-2}.

Communication between such discontinuous users flows on two common channels at most, one of them being of multiple access and the other a data broadcasting channel or just one multiple access/data broadcasting channel. (Data broadcast is like the program broadcast so that the transmitted information is received by all user stations although the message may be addressed only to one of them.) In the following part, the most important applications of effective and flexible multiple channel access will be discussed.

It is often possible in practical communication networks to create a common channel with multiple access, and even more, there are cases where this is an obvious solution. Let us overview now the most important cases and let us sum up the most important features of the corresponding multiple access and data broadcasting channels. The three most characteristic examples are:

- satellite system used as repeater,
- terrestrial radio network,
- local cable network.

Geostationary satellite is an obvious solution for telecommunication among user population widely spread over a certain area of the Earth (see Fig. 13.5.)

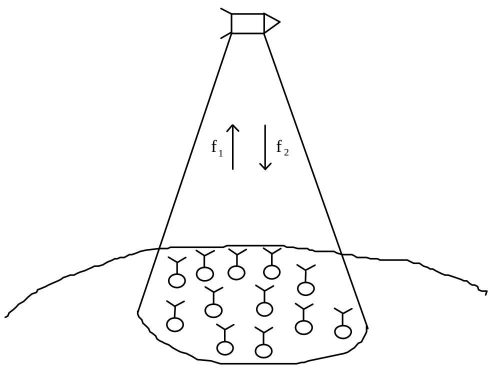

Fig. 13.5 Satellite Channel with Multiple Access

Satellite stations are working as repeaters, i.e. they receive users' messages on carrier frequency f_1 and transmit them back on frequency f_2. One of the specific features of the satellite channel is that everybody can listen to its own transmission so that he is automatically informed whether the packet (message) has successfully arrived to its destination or whether it collided during the multiple access with the packets of other users and it was therefore damaged. (The packet may of course be damaged by noise however this cannot be concluded from the backward information.) Another specific feature is that the propagation time is great in comparison with the packet time. The entire (two-way) propagation time is between 0.24-0.27 s. Supposing the channel data rate to be 32 kbit/s and taking a packet of 1000 bits, the propagation time is almost ten times longer than the packet time.

Terrestrial radio networks are usually built of one central (base) station and several users (often mobile) as is shown on Fig. 13.6. In the direction from users to the base station, there is a multiple access radio channel operating at f_1, while in the opposite direction a data broadcast channel on f_2 is used. Unlike in satellite systems, the users are not automatically provided with information about the success or fail of the transmission of their packets, this must be confirmed by the base station e.g. by so called positive acknowledgement.

The other characteristic is that the propagation time is short as compared to the packet time. Let us show a numerical example: suppose we want to transfer a 1000 bit packet to a distance of 32 km with 9600 bit/s data rate (which is a considerably high rate used in telephone networks and radiotelephone channels, as well). The propagation time for that distance will be 10^{-4} s which is about three decades less than the 0.1 s packet time. This may be important when the network topology provide the users to listen to each others transmission and thus making use of such an information. Methods of sensing the transmission (so called carrier sense) will be discussed in chapter 13.5.2.

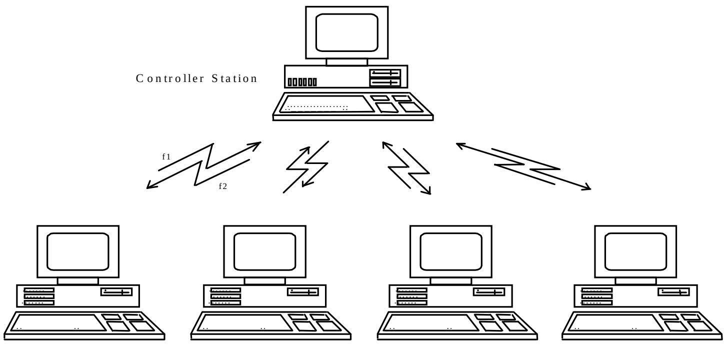

Fig. 13.6 Terrestrial Radio Data Transmission System

The third example is taken from the local area networks. A bus-structured local network is shown on Fig. 13.7. Here, the communication channel is a coaxial cable terminated at both ends with matching resistors. Stations are connected to the cable via line drivers and receivers.

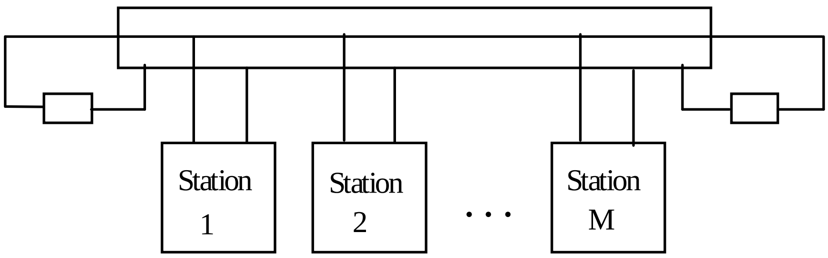

Fig. 13.7 Multiple Access via Wired Bus Structure

Main features of the cable channel are the high data rate (some Mbits/s) and low propagation time because of the short distance (it is reasonable to build the cable networks inside one building or between some buildings standing near each other). Thanks to the bus structure, users can check whether the channel is idle before sending their own packet and this information is quite reliable because of the short propagation time. The users can also listen to their own transmission and verify whether the transmission was correct or not. Thus the advantages of the satellite and terrestrial systems seem to be unified in this application.

13.5.1 Aloha-Type Random Access Procedures

Aloha is the most known and the simplest random access method. It has two versions, one of them is called *pure* and the other *slotted* Aloha. ('Aloha' is a Hawaiian greeting and it is used since the procedure has been worked out and tested first at the University of Honolulu.)

Any Aloha-user sends his packet immediately after it is ready. The packet starts with a 'header' containing the terminal address (identifier) and is protected by an error-detecting code (some kind of cyclic code). The central controller checks whether the packet has not collided (overlapped) with the packet of another user(s). Note that random bit errors result also in failed transmission.

Successful transmission is acknowledged by the central station or the lack of acknowledgement informs the user(s) that there was a collision. In the latter case, the user tries to repeat the transmission after a random delay. A possible process flow is illustrated in Fig. 13.8.

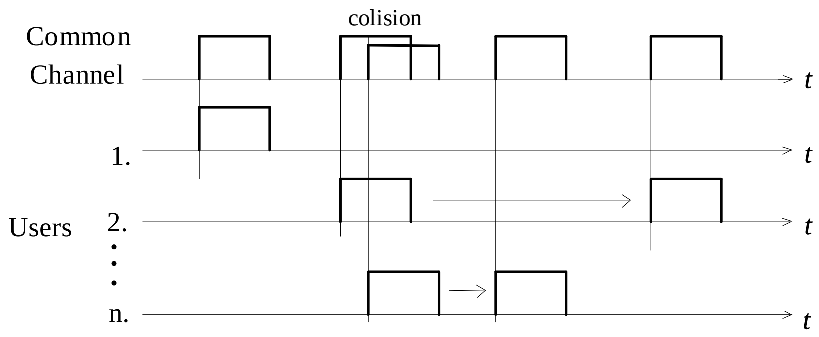

Fig. 13.8 An Example of Aloha Procedure

The advantage of the pure Aloha lies in its simplicity and acceptable performance in the case of low number of terminals. Slotted Aloha is an improved version which defines a time grid equal to the packet time. The length and the position of the time slots are known to the users, i.e. there is a kind of synchronism but still they do not co-operate with each other. The only difference compared to the pure Aloha is that the user has to send his packet(s) precisely inserted into the time slot(s). It is easy to see that the sending will be either successful or there shall be a full overlap with other packet(s). As a result, the channel efficiency will be higher since the 'vulnerable' time interval (when the packet may collide because of the start of another transmission) is halved.

13.5.2 Carrier Sense Procedures

Carrier sensing procedures form another group of random access methods. Short term for this group is CSMA (carrier sensing multiple access).

Suppose a network with star topology and (like in the Aloha) users communicating just with a central station. However, the users can listen to others or at least they are able to detect whether a transmission is on. Under such a condition, a significant number of collisions is avoided since the users examine the channel status before sending their packets and attempt the transmission only after they found the channel empty (no carrier detected).

Depending on what the user do after having examined the channel, several procedures may be followed. The simplest of them is the so called *non persistent* procedure which goes on according to the following rules:

a) If the channel is idle at the time the message is ready for transmission, the packet is sent.

b) If the channel is busy, user checks it later and repeats the procedure above.

It can be seen that carrier sensing cannot completely remove all the collisions since -due to the finite propagation delay and detection time- the users may detect the channel idle although it is already busy. If the packet time is denoted as T and the sum of the propagation delay and detection time as $\boldsymbol{a}$, it is obvious that the lower is the ratio a/T, the less will be the number of collisions and thus the better will be the channel utilization.

13.5.3 Conflict Resolving Algorithms

When distributed control is necessary, conflict resolving methods are used. The basic idea of these methods is the definite effort to resolve any conflict caused by simultaneously occurring demands, i.e. that it is a primary aim that channel has to be allocated to the users taking part in the collision. For this purpose, new users are not allowed to transmit until the conflict is resolved. The specific feature of conflict resolving algorithms is that if channel utilization is lower than the value specified for a given procedure then the operation is stable. (For the Aloha-type procedures, when the input traffic increases, the system may become unstable: propagation delay of packets increases, channel utilization decreases, and the channel may be 'blocked'.)

Control questions

1. What is the procedure for frequency division multiplexing ?
2. Why is polling advantageous as compared with static TDMA ?
3. What are the main practical cases of multiple channel access and what are the main features of these cases ?
4. Why is carrier sensing multiple access more advantageous than the Aloha method ?

References

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