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Department of  
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networks and systems

## **TRANSPORT TELECOMMUNICATION NETWORKS**

Methodical guidelines for performing the course work for students of the specialty  
5B071900 - Radio engineering, electronics and telecommunications

Almaty, 2018

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Methodical guidelines contain tasks and guidance for performing the course work.

Methodical guidelines are designed for students of the specialty 5B071900 Radio engineering, electronics and telecommunications

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## **Introduction**

The course «Transport telecommunications networks» is designed for in-depth training of students of the specialty "5B071900 Radio Engineering, Electronics and Telecommunications".

The main method of studying the course is to work independently with teaching aids and textbooks. The course requires performing of a course work.

For assessment of knowledge on theoretical and practical parts the students take an examination.

In recent years, demand for connection to broadband access networks has increased dramatically. One of the main reasons for this growth was the popularity of digital television and video content, which in turn is stimulated by lower prices and improved quality of modern flat screen TVs. Virtually all new LCD or plasma TV panels with a diagonal of more than 32 inches are capable of displaying a high-definition video image (HDTV).

The abbreviation PON stands for Passive Optic Network. The essence of PON technology lies on the fact that a passive optical network of a tree topology is created between the central node that provides connection to the backbones (IP, SDH, ATM) and subscriber nodes. From the central PON card one optical fiber leaves, which is divided by means of optical splitters into several dozen subscriber devices.

The downstream (from the center to the subscribers) and the upstream (from the subscriber to the center) are transmitted in the same fiber at different wavelengths. The downstream is a broadcast, public-key encryption is used to protect information. The upstream uses a Time Division Multiple Access (TDMA) protocol. The bandwidth in the ascending and descending streams is dynamically distributed among the subscribers.

## **Theme of the course work "The PON network design"**

### **1 Basic concepts of the PON network**

#### **1.1 Principles of PON operation**

The basic idea of the PON architecture is to use only one OLT transceiver module to transmit information and receive information from the ONT subscriber units. The number of subscriber units connected to one OLT transceiver module can be as large as the power budget and the maximum speed that the transceiver equipment allow. To transfer the flow of information from the OLT to the ONT - direct (downstream) flow - the wavelength is 1490 nm. Conversely, data streams from different subscriber nodes to the central node that together form the reverse (upstream) stream are transmitted at a wavelength of 1310 nm. For transmission of forward and reverse flows one optical fiber is used, the bandwidth of which is dynamically distributed among subscribers. WDM multiplexers have built-in OLT and ONT and separate outgoing and incoming streams.

##### *Direct flow.*

The direct stream at the level of optical signals is a broadcast. Each ONT, reading address fields, selects from this shared stream the information intended only to it. In fact, we are dealing with a distributed demultiplexer.

##### *Reverse flow.*

All ONT subscriber nodes implement transmission in the reverse stream at the same wavelength using the multiple access concept. In order to exclude the possibility of crossing signals from different ONTs, each of them is allocated its own time slot or sets its own schedule for transmitting the bottom, taking into account the delay correction associated with the removal of this ONT from OLT. This task is solved by the TDMA MAC protocol for the BPON standard, the MPDR protocol for EPON.

#### **1.2 Architecture of PON networks**

The development of the Internet, including the emergence of new communication services, contributes to the growth of data streams transmitted over the network and forces operators to look for ways to increase the carrying capacity of transport networks. Choosing a solution, it is necessary to take into account:

- diversity of subscriber needs;
- potential for network development;
- economy.

In the developing telecommunications market it is dangerous both to make hasty decisions, and to wait for the emergence of a new modern technology. Such technology has already appeared - this is the technology of passive optical networks PON.

The PON access network based on a tree fiber optic cable architecture with passive optical couplers on the nodes may be the most economical and capable of providing broadband transmission of a variety of applications. At the same time, the PON architecture has the necessary efficiency of building up both nodes of the network and throughput, depending on the present and future needs of subscribers.

The construction of access networks now mainly goes in four directions:

- networks based on the existing copper telephone pairs and xDSL technology;
- hybrid fiber-coaxial networks (HFC);
- wireless networks;
- fiber optic networks.

The use of constantly improving xDSL technologies is the simplest and inexpensive way to increase the capacity of an existing cable system based on copper twisted pairs. For operators, when it is required to provide a speed of up to 1-2 Mb/s, such a path is the most economical and justified. However, the transmission speed of up to tens of megabits per second on existing cable systems, taking into account long distances (up to several km) and poor quality of copper, is not an easy and rather expensive solution. Another traditional solution is hybrid fiber-coaxial networks (HFC, Hybrid Fiber-Coaxial). Connecting multiple cable modems to one coaxial segment leads to a reduction in the average cost of building network infrastructures per user and makes such solutions attractive. In general, there remains a constructive limitation of bandwidth. Wireless access networks can be attractive where technical difficulties arise for the use of cable infrastructures. Wireless communication by its nature has no alternative for mobile services. In recent years, along with traditional solutions based on radio and optical Ethernet access, Wi-Fi technology has become increasingly widespread, allowing a total bandwidth of up to 10 Mbps and in the short term up to 50 Mbps. It should be noted that for the three listed areas, further increase in the network capacity is associated with great difficulties, which are absent when using a transmission medium such as fiber. Thus, the only way to lay the network's ability to work with new applications requiring an increasing transmission speed is to lay the optical cable (OC) from the central office to the home or to the corporate client. And 5 years ago it was considered extremely expensive. However, at the present time, due to a significant reduction in prices for optical components, this approach has become relevant. Today, laying out the OC for the organization for the access network has been beneficial both for the renovation of the old ones and for the construction of new access networks. There are many options for choosing fiber-optic access technology. Along with the traditional solutions based on optical modems, optical Ethernet, Micro SDH technology, new solutions have emerged using the architecture of PON's passive optical networks.

### 1.3 The main topologies of optical access networks

There are four main topologies for building optical access networks: “point-to-point”, “ring”, “tree with active nodes”, and “tree with passive nodes”.

#### 1.3.1 Point-to-Point (P2P).

Topology P2P (figure 1.1) does not impose restrictions on the used network technology. P2P can be implemented for any network standard, as well as for proprietary solutions, for example optical modems. In terms of security and protection of transmitted information, P2P connection ensures maximum security of subscriber units. Since OC needs to be laid individually to the subscriber, this approach is the most expensive and attractive mainly for large subscribers.

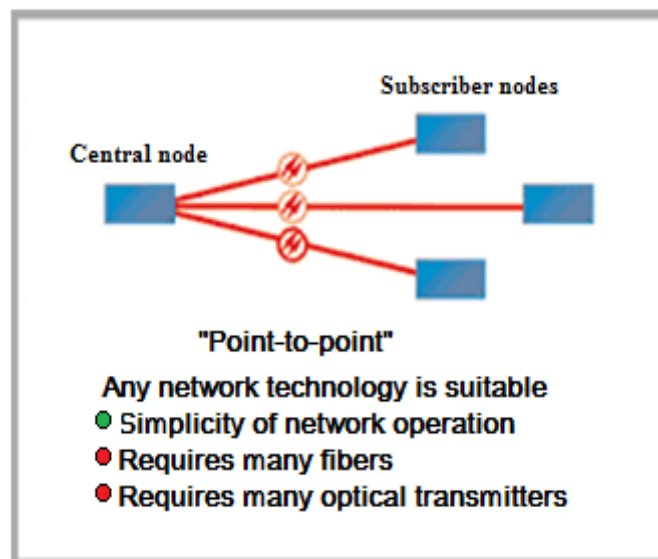


Figure 1.1 – «Point-to-point» topology

#### 1.3.2 Ring.

The «ring» topology (figure 1.2) based on SDH has proven itself in urban telecommunications networks. However, in access networks, not everything is as well. If the location of the nodes is planned during the design phase, when building a city highway, it is impossible to know in advance where, when and how many subscriber nodes will be installed in access networks. With random territorial and temporary connection of users, the ring topology can turn into a severely broken ring with many branches, new subscribers are connected by breaking the ring and inserting additional segments. In practice, often such loops are combined in one cable, which leads to the appearance of rings that are more similar to a broken line - "collapsed rings", which significantly reduces the reliability of the network. In fact, the main advantage of ring topology is minimized.

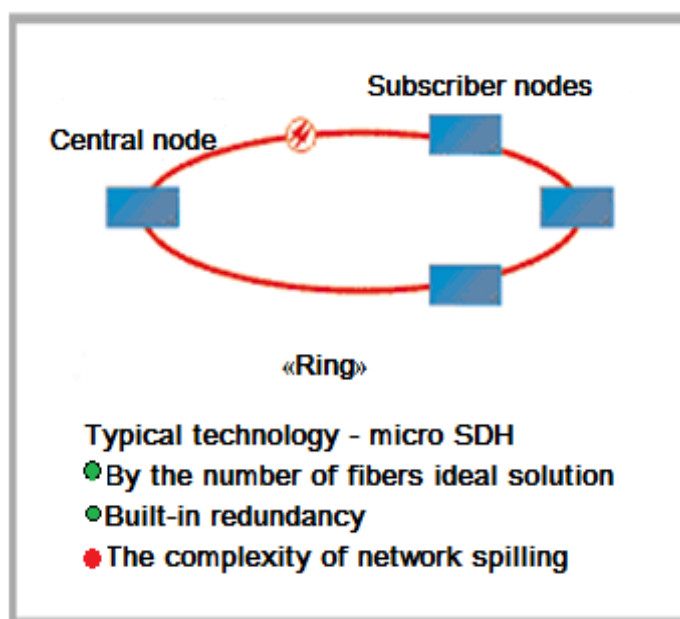


Figure 1.2 – «Ring» topology

### 1.3.3 Tree with active nodes.

Tree with active nodes (figure. 1.3) – This is an economic solution in terms of fiber usage. This solution fits well within the framework of the Ethernet standard with a hierarchy of speeds from the central node to subscribers 1000/100/10 Mbps (1000Base-LX, 100Base-FX, 10Base-FL). However, in each node of the tree there must be an active device (for IP networks, a switch or a router). Optical Ethernet access networks, mainly using this topology, are relatively inexpensive. The main disadvantage is the presence of intermediate nodes active devices requiring individual power.

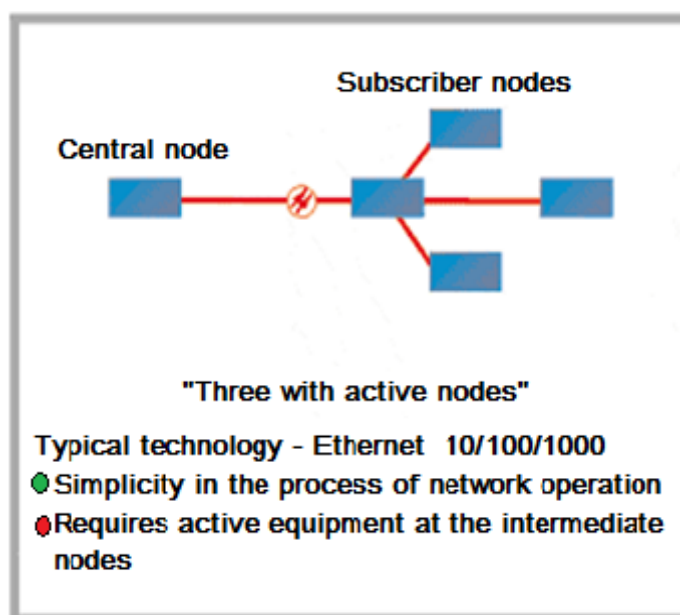


Figure 1.3 – 1.3.3 Tree with active nodes topology

#### 1.3.4 Tree with passive optical network PON (P2MP).

PON architecture solutions (figure 1.4) use the P2MP (point-to-multipoint) logical topology, which is the basis of PON technology, a single fiber-optic segment of a tree architecture can be connected to one port of the central node, covering dozens of subscribers. At the same time, compact, fully passive optical splitters (splitters) are installed in the intermediate nodes of the tree and do not require power and maintenance.

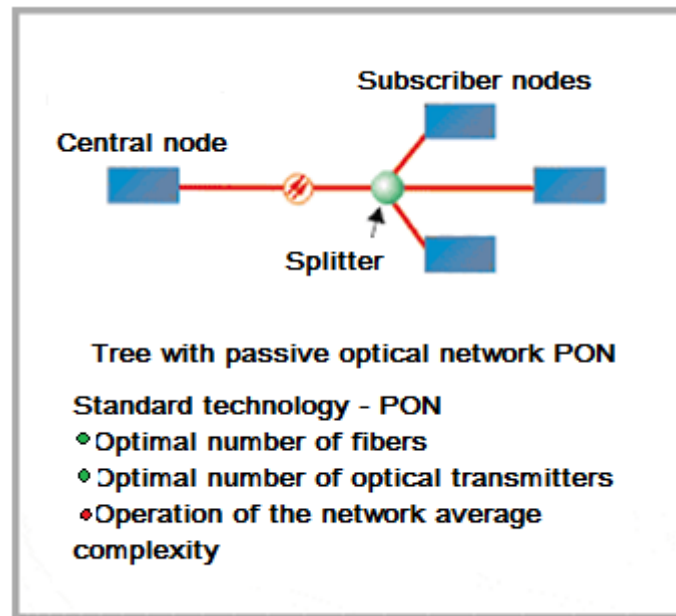


Figure 1.4 – “Tree with passive optical network” topology

It is well known that PON allows to save on the cable infrastructure by reducing the total length of optical fibers, since only one fiber is used from the central node to the splitter. To a lesser extent, attention is paid to another source of savings: a reduction in the number of optical transmitters and receivers in the central node. Meanwhile, the saving of the second factor in some cases is even more significant. So, according to NTT, the PON configuration with a splitter in the central office in the immediate vicinity of the central node is more economical than the point-to-point network, although the fiber length is practically shortened. Moreover, if the distances to subscribers are not large (as in Japan), taking into account operating costs (in Japan this is an important factor), it turns out that PON with a splitter in the central office is more economical than PON with a splitter close to subscriber nodes. The P2MP tree topology makes it possible to optimize the location of optical splitters based on the real location of subscribers, the costs of laying OC and the operation of the cable network.



## 2 The tasks of the work

Task 1. Reveal PON technology. Construct a network diagram, describe all the elements included in the network.

Task 2. Designing a PON network for urban areas where subscribers are located tightly. The design was provisionally taken by plots from the city of Almaty, proposed in application A. OLT - is located at the crossroads of two roads - Kurmangazy and Muratbayeva.

The projected site is selected from table 2.1, according to the first letter of the student's last name. The maps of the projected sections are given in application A.

The student designs only individual quarters on the map on the last number of the record book (table 2.2).

The number of potential subscribers in residential buildings is given in the table – 2.3.

Below, in *Example 1*, an example is given for designing a PON network for urban areas and an example of calculations.

Table 2.1 - Scope table selection table

The first letter of the surname	Site number
A – E	1
Ж – М	2
Н – Т	3
У – Ч	4
Ш – Я	5

Table 2.2 – Quarterly selection chart

The last number of the record book	Quarter Number
0	1-2-3-4
1	5-6-7-8
2	1-2-4-7
3	3-5-7-8
4	1-3-6-8
5	2-4-5-7
6	2-4-6-8
7	1-3-5-7
8	1-4-5-8
9	1-3-4-8

Table 2.3 – Number of subscribers in apartment houses

№ house	Number of floors	Number of entrances	Number of apartments
40-50	4	4	48
51-60	5	2	30
61-70	6	3	72
71-80	5	2	40
81-90	4	4	64
91-100	3	3	36
101-110	8	2	64
111-120	8	2	64
121-130	9	2	54
131-140	4	3	48
141-150	5	2	40
151-160	6	4	72
161-170	6	4	72
171-180	4	4	64
181-190	5	2	40
191-200	4	3	48

*Example 1.* Designing a PON network for urban areas.

### 3 Example. Designing a PON network for urban areas

#### 3.1 Selecting equipment, calculation of the quantity of OLT, number of optical ports and quantity of fibers

1) Calculation of the amount of equipment is made by the formula (3.1):

$$N_{OLT} = \frac{N_{AB}}{m \times N_{\Pi}}; \quad (3.1)$$

$$N_{OLT} = \frac{810}{32 \times 8} = [3,16] = 4,$$

where, m - the number of subscribers supported by a single optical OLT port;

$N_{\text{subscriber}}$  – Number of potential subscribers;

$N_{\Pi}$  – Number of optical ports OLT.

In our case, we took the OLT with  $N_{\Pi} = 8$  optical ports, each which supports  $m=32$  subscribers, company ZyXEL OLT-1308H

*Active equipment OLT* is installed in the access node.



Figure 3.1 - ZyXEL OLT-1308H

Characteristics:

1) 8 GEAPON-interfaces (SC-type connector), supporting up to 32 ONUs on each port.

2) Wavelength: 1.31  $\mu\text{m}$  for upstream channel & 1.49  $\mu\text{m}$  for downstream channel.

3) 8 ports of 1000Base-T.

4) One 10 / 100Base-T port for control.

5) One DB9 RS-232 port for console connection.

Optical power budget:

1) For ONU in 10km - not less than 29 dB.

2) For ONU in 20km - not less than 30.5 dB.

The sensitivity of the PON port receiver:

2) Sensitivity: max. -27 dBm.

3) Overload level: min.-6 dBm.

Passive equipment ONU is installed in the subscriber's apartment.

ONU-PSG1182-22– GPON modem with Ethernet switch and two telephone sockets.

Constructive features:

- optical port SC/UPC GPON ITU-T G.984;
- four 10 / 100Base-TX ports;
- two FXS ports for making calls via VoIP;
- status indicators of device' ports;
- setting on a desk or on the wall.

Optical characteristics:

1) Optical cable: G.653 / G.657, single-fiber.

2) Wavelength: 1310 nm (from the subscriber), 1490 nm (to the subscriber).

3) WAN port bandwidth to subscriber, from subscriber: 2488 Mbps: 1244 Mbps.

4) Maximum distance: 20 km.

5) Compliance with the standard: Class B + ODN with a sensitivity of -8 ~ -28 dBm.

6) Transmitter Optical Power: 0.5 dBm ~ 5 dBm.

2. Calculation of the number of optical ports is carried out by the formula (2):

$$N_p = \frac{N_{Sub}}{m}; \quad (3.2)$$

$$N_p = \frac{N_{Sub}}{m} = \frac{810}{32} = [25,31] = 26.$$

This formula produces 26 ports, but our equipment is designed for 8 ports and each of them can support 32 subscribers, and we need to take into account the reserves. In this case, we use the following formula (the ports depend on the number of OLTs):

$$N_p = N_{OLT} \times N_{Port} = 4 \times 8 = 32.$$

And we get  $N_p = 32$  ports.

The number of optical fibers contained in the optical cable, routed from the OLT equipment to the customer building is equal to the number of optical ports of the OLT equipment. Therefore, the amount of OF is 32.

### 3.2 Calculation of the GPON network capacity

The load created by all users is determined from the expression:

$$B_0 = (B_{DR} \times k_{DR} + B_{VoIP} \times k_{VoIP} + B_{VoD} \times k_{VoD}) \times N_{Sub}, \quad (3.3)$$

where  $B_{DR}$  – VFD is the data rate, Mbps.;

$B_{VoIP}$  – Speed of traffic in IP-telephony, Kbps ;

$B_{VoD}$  – the flow rate in the networks of "Video on Demand", Mbps;

$N_{Sub}$  - number of residents subscribers;

$k$  – Coefficient determining the number of subscribers using a particular service from the total number of subscribers. So for VoIP service the number of users will be 20% of the total number of subscribers, for DT - 70%, for VoD - 10%.

Load calculation:

1) Transmission of digital television:

2)

$$B_{DR} = N_{SUB} \times 0,7 \times 10 \text{ Mbpc}; \quad (3.4)$$

$$B_{DR} = 810 \times 0,7 \times 10 \text{ Mbps} = 708,75 \text{ Mbps}.$$

3) Voice transmission: Mbps

$$B_{VoIP} = N_{sub} \times 0,20 \times 128 \text{ Kbps}; \quad (3.5)$$

$$B_{VoIP} = 810 \times 0,20 \times 128 \text{ Kbps} = 2,53 \text{ Mbps}.$$

4) Video transmission on demand:

$$B_{VoD} = N_{sub} \times 0,10 \times 2 \text{ Mbps} ; \quad (3.6)$$

$$B_{VoD} = 810 \times 0,10 \times 2 \text{ Mbps} = 20,25 \text{ Mbps} .$$

Determine the total load:

$$B_0 = (B_{DR} + B_{VoIP} + B_{VoD}) ; \quad (3.7)$$

$$B_{\Sigma} = (B_{DR} + B_{VoIP} + B_{VoD}) = 708,75 + 2,53 + 20,25 = 731,53 \text{ Mbps}.$$

This is the load coming from all subscribers of the network.

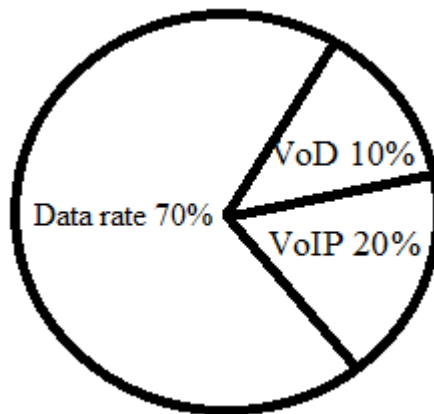


Figure 3.2 – Load distribution diagram

### 3.3 Calculation of the optical budget

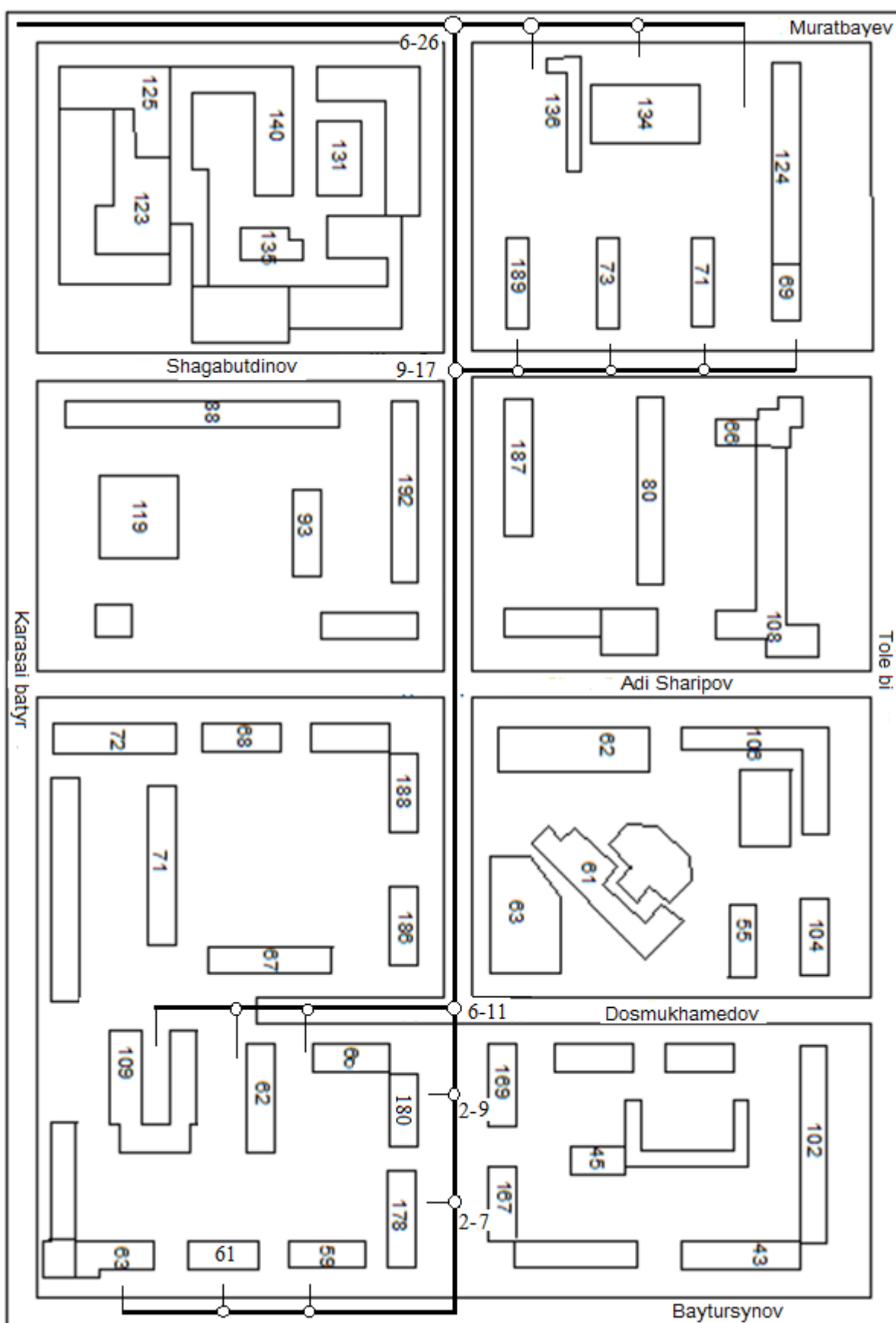


Figure 3.3 – The route of the Fiber Optic Communication System

Table 3.1 – Number of subscribers according to the variant

House No.	Number of floors	Number of entrances	Number of apartments	Number of Fibers
59,60	5	2	30x2	1x2=2
61,62,63,69	6	3	72x4	3x4=12
71,73	5	2	40x2	2x2=4
109	8	2	64	2
124	9	2	54	2
134,136	4	3	48x2	2x2=4
178,180	4	4	64x2	2x2=4
189	5	2	40	2
		Total:	810	32

Number of couplings  $N_{muf}=14$  pcs.

Here is an example, of the attenuation calculation for the terminal subscribers from the OLT to the Baytursynov street 63.61.59 houses.

Table 3.2 – The amount of insertion loss

	OLT63	OLT61	OLT59
$L$ , km	1,67	1,6	1,57
$N_P$ , pcs	4	4	4
$N_C$ , pcs	6	5	5
Subscriber	72	72	30
Number of fibers	3	3	1
Splitter	1x32	1x32	1x32
Number of splitters	3	3	1

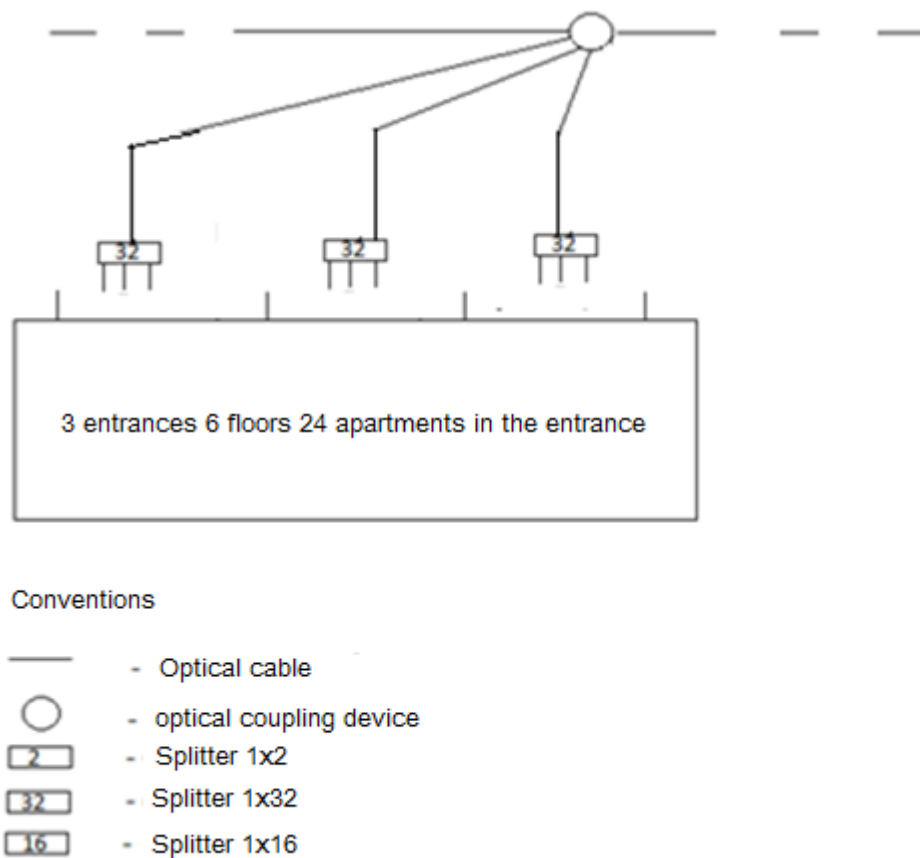


Figure 3.4 - PON network construction scheme in 61, 63apartments

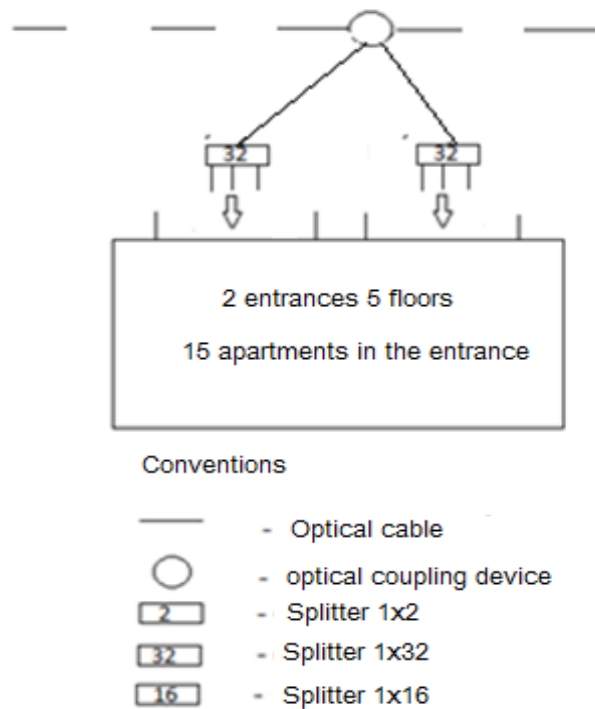


Figure 3.5 - PON network construction scheme for the flat 59



We calculate the optical budget by the formula (3.8):

$$A_{\Sigma} = L_i \cdot \alpha + N_p \cdot A_p + N_C \cdot A_C + A_{dev}, \text{ dB}, \quad (3.8)$$

where  $A_{\Sigma}$  – total losses in the line (between OLT and ONU), dB;

$L_i$  – Length of i-section, km;

$\alpha$  – Optical cable attenuation coefficient dB / km;

$N_p$  – number of demountable connections;

$A_p$  – Average losses in the plug-in connection (the detachable connection can be at least 3 or more: for the subscriber, for the splitters and OLT), dB;

$N_C$  – Number of welded joints;

$A_C$  – Average loss in welded connection, dB;

$A_{dev}$  – Losses in the optical splitter, dB;

The first term refers to the total losses in the optical cable, the second - to the losses in the connectors, the third - to the losses on the welds, and the fourth - the losses in the splitters.

Table 3.3 – Values of loss factors

	Insertion loss
OK attenuation coefficient at a wavelength of 1310 nm	0,35 dB /km
OK attenuation coefficient at a wavelength of 1490 nm	0,27 dB /km
Losses in plug-in connections	0,3 dB
Losses on welded joints	0,08 dB
Maximum losses in a 1x32 splitter	18 dB

Let's substitute the numerical values without taking into account the stock in the formula on the length of 1310nm wavelength:

$$OLT - ONT_{63} : A_{\Sigma 1} = (1,67) \cdot 0.35 + (4 \cdot 0.3) + (6 \cdot 0.08) + 18 = 20,2645 \text{ dB};$$

$$OLT - ONT_{61} : A_{\Sigma 2} = (1,60) \cdot 0.35 + (4 \cdot 0.3) + (5 \cdot 0.08) + 18 = 20,16 \text{ dB};$$

$$OLT - ONT_{59} : A_{\Sigma 3} = (1,57) \cdot 0.35 + (4 \cdot 0.3) + (5 \cdot 0.08) + 18 = 20,1495 \text{ dB}.$$

At a wavelength of 1550 nm is:

$$OLT - ONT_{63} : A_{\Sigma 1} = (1,67) \cdot 0.27 + (4 \cdot 0.3) + (6 \cdot 0.08) + 18 = 20,1309 \text{ dB};$$

$$OLT - ONT_{61} : A_{\Sigma 2} = (1,60) \cdot 0.27 + (4 \cdot 0.3) + (5 \cdot 0.08) + 18 = 20,032 \text{ dB};$$

$$OLT - ONT_{51} : A_{\Sigma 3} = (1,57) \cdot 0.27 + (4 \cdot 0.3) + (5 \cdot 0.08) + 20,3 = 20,0239 \text{ dB}.$$

The calculation of the loss budget should confirm that for each circuit the total loss (including the stock) does not exceed the dynamic range of the system, i.e:

$$P = P_{out.min} - P_{in} \geq A_{\Sigma} + P_{stock} , \quad (3.9)$$

where  $P$  – is the dynamic range of PON, dB;  
 $P_{out.min}$  – Minimum transmitter output power OLT, dBm;  
 $P_{in}$  – allowable power at the receiver input ONT, dBm;  
 $A_{\Sigma}$  – Total line losses (Between OLT and ONT), dB;  
 $P_{stock}$  – Operational stock PON, dB.

At a wavelength of 1310 nm:

$$P = 2,5 - (-28) \geq 20,2645 + 7 \text{ dB};$$

$$P_{63} = 30,5 \geq 27,2645 \text{ dB};$$

$$P_{61} = 30,5 \geq 27,16 \text{ dB};$$

$$P_{59} = 30,5 \geq 27,1495 \text{ dB};$$

At a wavelength of 1490nm:

$$P = 0,5 - (-28) \geq 20,1309 + 7 \text{ dB};$$

$$P_{63} = 28,5 \geq 27,1309 \text{ dB};$$

$$P_{61} = 28,5 \geq 27,032 \text{ dB};$$

$$P_{59} = 28,5 \geq 27,0239 \text{ dB}.$$

The operational reserve should be provided in case of damage in the linear path, deterioration of transmission conditions and further development of the network. Usually a margin of 5-7 dB is taken, but if a significant number of users are expected to be connected to certain network segments, then the margin should be clearly larger.

From the above calculations it is clear that this projected access network will work.

The maximum signal level required to calculate the optical budget (at the output of the OLT and ONU station terminal transmitter) is given in tables 3.3 and 3.4.

Table 3.3 – OLT-1308H Technical specifications

Transmitter Power	from +2.5 to +5 dB
Receiver Sensitivity	from -27 to -6 dB
Optical power budget upstream/downstream	30,5 dB /30 dB

Table 3.4 – ONU-PSG1182-22 Technical specifications

Transmitter Power	from +0,5 to +5 dB
Receiver Sensitivity	from -28 to -8 dB
Optical power budget upstream/downstream	30,5 dB /30 dB

### 3.4 Development of communication scheme

The communication scheme is developed taking into account the calculated number of OLT equipment, the number of optical ports (optical fiber) and the number of optical splitters.

Build a tree topology of the PON network.

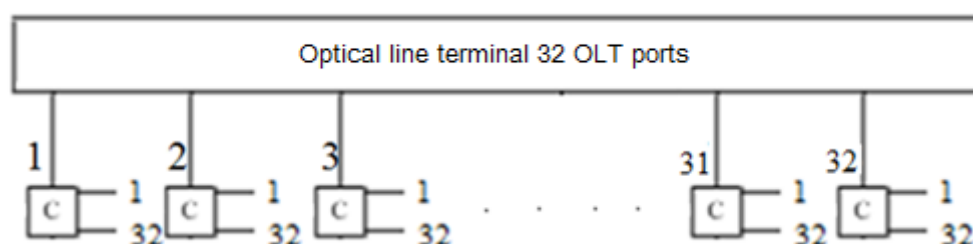


Figure 3.6 – Tree topology of the PON network

According to the tree topology, a communication scheme is developed, which is shown in figure 3.7.

Optical fibers shown by a solid line which is allocated to the expansion of the network. Optical fibers are represented by a different type of line designed to organize the communication of 810 subscribers. There are optical crosses in every house.

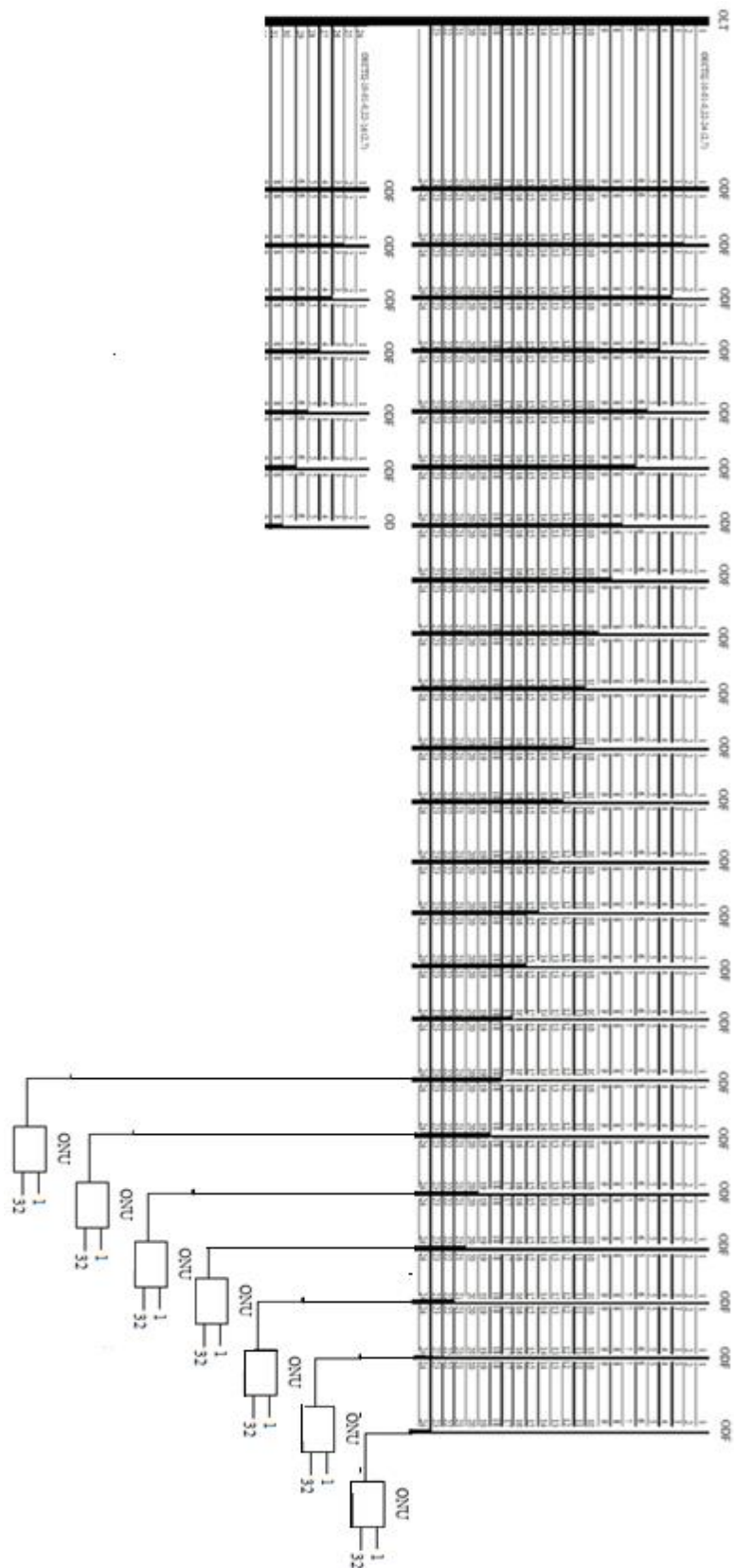


Figure 3.7 – The scheme of organization of PON network communication

Task 3. Design PON network for private areas where subscriber density is not large. The sites were taken conditionally for the design. Maps of sites are specified in Application B.

The third task assignments is the loss budget calculation for each branch, and determination of optimal dividing coefficients for all splitters.

The planned site is selected from the table 3.1, according to the last number of the student record book. Maps of projected areas are given in Application B. The distance between subscribers is given in the table 3.2. Is selected by the first letter of the student's name.

Below, in *Example 4*, an example is given for designing a PON network for subscribers with low density.

Table 3.6

The last figure of the record book	Site number	The last figure of the record book	Site number
0	1	5	6
1	2	6	7
2	3	7	8
3	4	8	9
4	5	9	10

Table 3.7

Ln, km	A – E	Ж – М	Н – Т	У – Ч	Ш – Я
L1	1,0	1,0	2,5	1,7	2,0
L2	1,5	1,2	1,2	1,6	1,5
L3	1,25	1,1	0,9	1,7	1,1
L4	0,8	0,9	2,0	1,6	1,2
L5	0,5	0,75	1,3	1,7	1,3
L6	0,75	0,5	0,5	1,2	0,5
L7	0,9	1,25	0,6	0,5	0,9
L8	0,6	1,5	0,7	0,6	0,8
L9	0,7	0,8	0,3	0,3	0,4
L10	0,4	0,3	0,6	0,4	0,3

As usually the subscribers are at different distances from the headend, then, at a uniform power splitting in each splitter, the power at the input of each ONU will be different. The selection of the parameters of the splitters is connected with the need to obtain at the input of each subscriber terminal of the network approximately the same level of optical power, i.e. Build a so-called balanced network. This is fundamentally important for two reasons. Firstly, for the further development of the network it is important to have a steady supply of the attenuation in each branch

PON «tree». Secondly, if the network is not balanced, then the OLT station from different ONUs will receive in the general flow signals that are very different in level. The detection system is not able to process significant drops (more than 10-15 dB) of received signals, which will significantly increase the number of errors in the reception of the return flow.

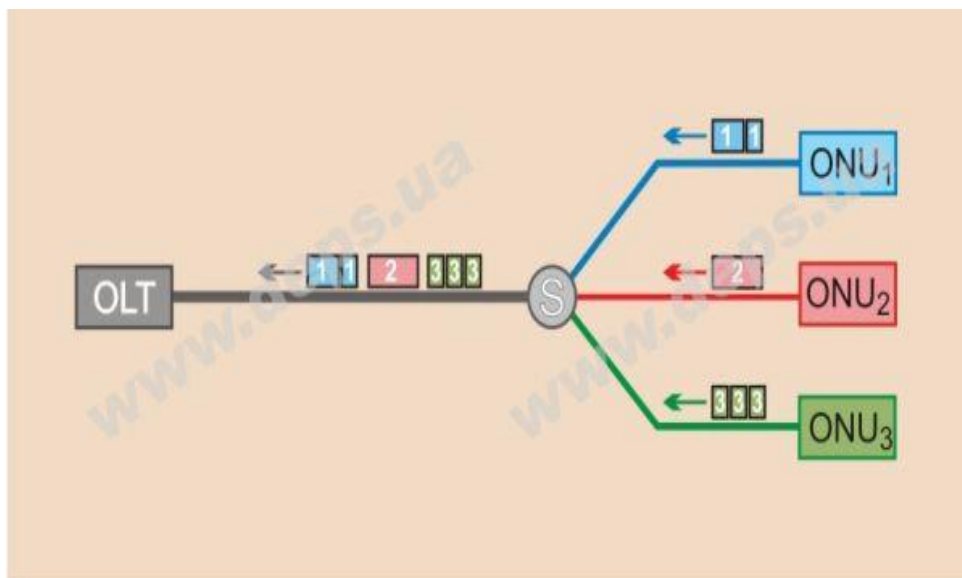


Figure 3.8 – Balanced PON

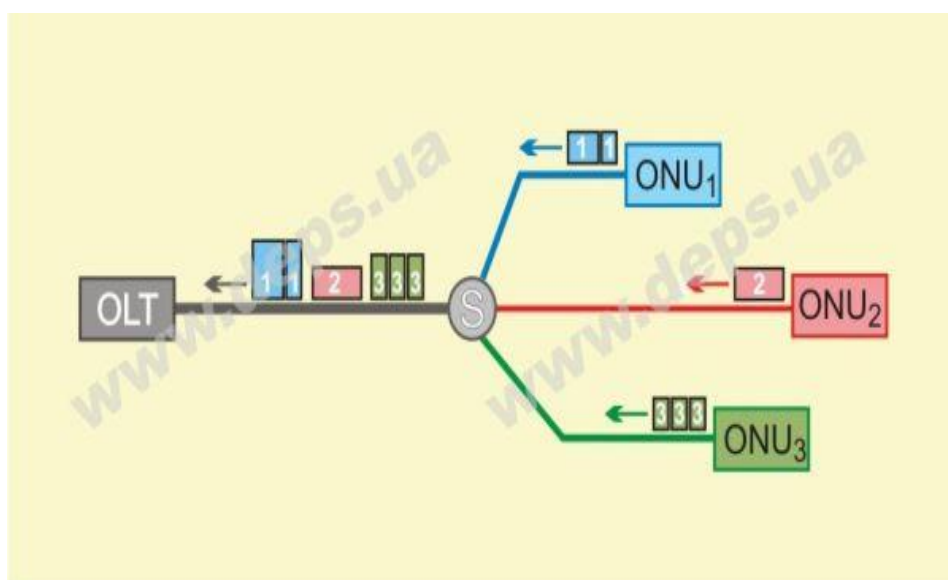


Figure 3.9 – Unbalanced PON

When choosing splitters division factors you need to know what losses will be introduced into the circuit at a given division factor. For an approximate determination of the insertion loss of two-way (1310nm and 1550nm) 1x2 splitters, we use the following reference table 3.3.

Table 3.3

Coefficient of division, %	Estimated insertion loss, dB	The difference in insertion loss between output ports, dB
50/50	3,7/3,7	0
45/55	4,2/3,2	1,0
40/60	4,8/2,8	2,0
35/65	5,4/2,4	3,0
30/70	6,2/2,0	4,2
25/75	7,1/1,6	5,5
20/80	8,2/1,3	6,9
15/85	9,7/1,0	8,7
10/90	11,7/0,7	11,0
5/95	15,2/0,5	14,7

*Note:* The tables show the maximum values of the insertion loss, which are higher than the real ones by a few tenths of a dB.

If you need to determine the insertion loss of the splitters with a large number of output ports or use with other division factors, you can use the estimated formula (3.10):

$$A_i = 10 \cdot \lg \left( \frac{100\%}{D\%} \right) + \log_2(N - 1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{D\%} \right), \text{ dB}, \quad (3.10)$$

where **D%** – Percentage of power output to this port, %;

**N** – Number of output ports;

**i** – Number of the output port.

*Example 2.* We calculate the attenuation introduced by the 1x2 splitter with the fission coefficient 33/67. Let's make the following calculation:

$$A_1 = 10 \cdot \lg \left( \frac{100\%}{33\%} \right) + \log_2(2 - 1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{33\%} \right) = 5,74 \text{ dB} ;$$

$$A_2 = 10 \cdot \lg \left( \frac{100\%}{67\%} \right) + \log_2(2 - 1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{67\%} \right) = 2,20 \text{ dB} .$$

*Example 3.* We calculate the attenuation introduced by the 1x4 coupler with a division factor of 10/25/30/35. Let's calculate for each of the four output ports:

$$A_1 = 10 \cdot \lg \left( \frac{100\%}{10\%} \right) + \log_2(4 - 1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{10\%} \right) = 11,70 \text{ dB} ;$$

$$A_2 = 10 \cdot \lg \left( \frac{100\%}{25\%} \right) + \log_2 (4-1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{25\%} \right) = 7,12 \text{ дБ} ;$$

$$A_3 = 10 \cdot \lg \left( \frac{100\%}{30\%} \right) + \log_2 (4-1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{30\%} \right) = 6,21 \text{ дБ} ;$$

$$A_4 = 10 \cdot \lg \left( \frac{100\%}{35\%} \right) + \log_2 (4-1) \cdot 0,4 + 0,2 + 1,5 \cdot \lg \left( \frac{100\%}{35\%} \right) = 5,44 \text{ дБ} .$$

It should be remembered that using the look-up table and calculating the above formulas will allow you to only approximately estimate the value of the insertion loss (the error is in the range 0.1 ... 0.4 dB). The specific values of the insertion loss for each splitter are given by the manufacturer, but the calculated values are also quite suitable for design.

Now we can proceed to the selection of the splitting factors of the splitters for a particular project and the calculation of the loss budget. For each optical line, we represent all the losses in the line in the form of the sum of the attenuation of all components:

$$A_{\Sigma} = (l_1 + \dots + l_n) \cdot \alpha + N_P \cdot A_P + N_C \cdot A_C + (A_{Los1} + A_{Losm}), \text{ dB} \quad (3.11)$$

where  $A_{\Sigma}$  – Total line losses (between OLT and ONU), dB;

$l_i$  – Length of i-section, km;

$n$  – number of sites;

$\alpha$  – Attenuation coefficient of optical cable, dB / km;

$N_P$  – Number of detachable connections;

$A_P$  – Average losses in the plug-in connection, dB;

$N_C$  – Number of welded joints;

$A_C$  – Average loss in welded connection, dB;

$A_{Los i}$  – Losses in the i-optical coupler, dB;

The first term refers to the total losses in the optical cable, the second - to the losses in the connectors, the third - to the losses on the welds, and the fourth - the losses in the splitters.

After that, we will calculate the attenuation for each circuit (from OLT to ONU) with respect to the first three terms and choose the splitting factor of the splitters so that the attenuation in each circuit is approximately the same.

The calculation of the loss budget should confirm that for each circuit the total loss (including the stock) does not exceed the dynamic range of the system, i.e. (form 3.9):

$$P = P_{out.min} - P_{in} \geq A_{\Sigma} + P_{reserve} ,$$



where  $P$  – Dynamic range PON, dB;

$P_{OUT\ min}$  – The minimum output power of the OLT transmitter, dBm;

$P_{IN}$  – Admissible input power ONU, dBm;

$A_{\Sigma}$  – Total line losses (between OLT and ONU), dB;

Preserve – Operating margin PON, dB.

The operational reserve should be provided in case of damage in the linear path, deterioration of transmission conditions and further development of the network. Usually a margin of 3-4 dB is taken, but if a significant number of users are supposed to connect to certain segments of the network, then the stock should be clearly larger.

The described sequence of calculations is best demonstrated by a simple example.

*Example 4.* Determine the parameters of the optical splitters and calculate the optical network budget for the PON project presented in the following figure. Losses in plug-in connections take  $AP = 0.3$  dB, welding losses -  $AC = 0.05$  dB, the attenuation coefficient of the optical cable is  $0.35$  dB / km at a wavelength of  $1310$  nm and  $0.22$  dB / km at a wavelength of  $1550$  nm. The lengths of the sections are  $l_1 = 4$  km,  $l_2 = 2$  km,  $l_3 = 2$  km,  $l_4 = 4$  km,  $l_5 = 6$  km.

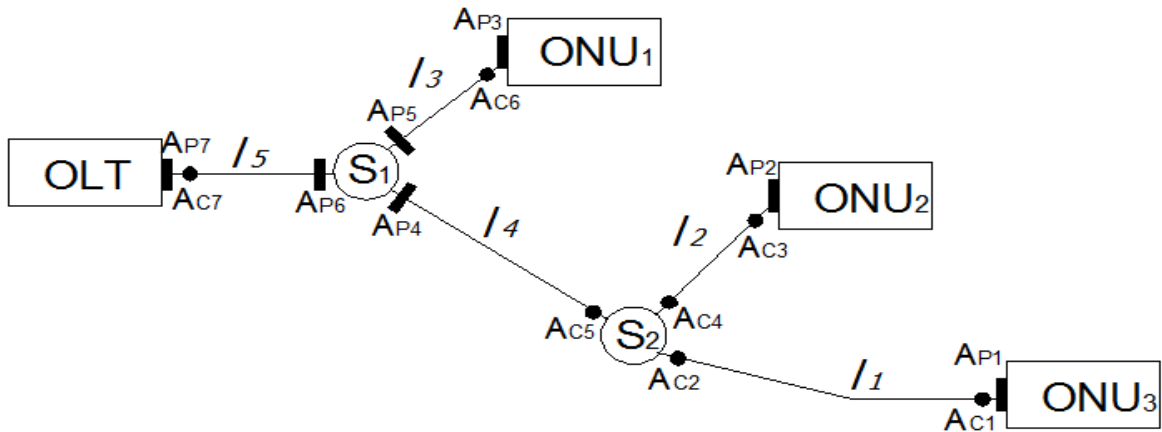


Figure 3.10 – PON project

We calculate the losses by the above formula for each of the three chains:

$$\text{OLT-ONU}_1: A_{\Sigma-1} = (6+2) \cdot \alpha + 4 \cdot A_p + 2 \cdot A_c + A_{Los-1} =$$

$$8 \cdot 0,35 + 4 \cdot 0,3 + 1 \cdot 0,1 + A_{Los-1} = 4,1 + A_{Los-1}.$$

$$\text{OLT-ONU}_2: A_{\Sigma-2} = (6+4+2) \cdot \alpha + 4 \cdot A_p + 4 \cdot A_c + A_{Los-1} + A_{Los-2} =$$

$$12 \cdot 0,35 + 4 \cdot 0,3 + 3 \cdot 0,1 + A_{Los-1} + A_{Los-2} = 5,6 + A_{Los-1} + A_{Los-2}.$$

$$\text{OLT-ONU}_3: A_{\Sigma-3} = (6+4+4) \cdot \alpha + 4 \cdot A_p + 4 \cdot A_c + A_{Los-1} + A_{Los-2} =$$

$$14 \cdot 0,35 + 4 \cdot 0,3 + 3 \cdot 0,1 + A_{Los-1} + A_{Los-2} = 6,3 + A_{Los-1} + A_{Los-2}.$$

*Note.* In calculations, a larger value of  $\alpha$  from the condition of the example ( $0.35$  dB / km) should be used.

We start from the far end and select the splitting factor of the splitter S2. The difference in losses without taking into account the splitters is  $6.3 - 5.6 = 0.7$  dB. From the look-up table, based on the difference in insertion loss between the output

ports, we select the closest value - 1.0 dB, which corresponds to the division ratio of 45/55.

*Note.* One should not particularly strive for a more accurate indication of the fission factor, for example, 47/53. Due to a significant spread of the parameters of the splitters, the insertion loss will be approximately the same as at 45/50. From the same table it can be seen that when 45% of the power is directed to ONU2, the insertion loss from S2 is 4.2 dB. To ONU3 will be sent 55% of the power, from S2 and the insertion attenuation will be 3.2 dB. Then:

$$\text{OLT-ONU}_1: A_{\Sigma-1} = 4,2 + A_{\text{Los-1}}.$$

$$\text{OLT-ONU}_2: A_{\Sigma-2} = 5,6 + A_{\text{Los-1}} + 4,2 = 9,8 + A_{\text{Los-1}}.$$

$$\text{OLT-ONU}_3: A_{\Sigma-3} = 6,3 + A_{\text{Los-1}} + 3,2 = 9,5 + A_{\text{Los-1}}.$$

The largest difference in levels is between the first and second circuits:  $9.8 - 4.2 = 5.6$  dB. From the look-up table we see that the nearest value of the difference in insertion loss between the output ports is 5.5 dB, which corresponds to a division ratio of 25/75. Substituting the insertion loss, respectively 7.1 dB and 1.6 dB, we get:

$$\text{OLT-ONU}_1: A_{\Sigma-1} = 4,2 + 7,1 = 11,3 \text{ dB};$$

$$\text{OLT-ONU}_2: A_{\Sigma-2} = 9,8 + 1,6 = 11,4 \text{ dB};$$

$$\text{OLT-ONU}_3: A_{\Sigma-3} = 9,5 + 1,6 = 11,1 \text{ dB}.$$

Thus, the splitting factors of the splitters S1 and S2 are calculated, and the network can be considered balanced, because the spread between the attenuation of the circuits is minimal.

Let's check whether the budget of losses, including the stock, does not exceed the dynamic range of the system. Given that for the PON UTSTARCOM system, the dynamic range is 29 dB, we get:

$$29 \text{ dB} \geq (11,4 + 3) \text{ dB}.$$

*Note.* The value of  $A_{\Sigma}$  is used for the worst case, in this example for the OLT-ONU1 circuit (11 dB). *Примечание.*

If the condition is confirmed for the circuit with the largest attenuation - OLT-ONU2, therefore, it will be observed for other circuit variants.

As can be seen from the example, the task of calculating the splitters and the power budget does not involve complex mathematical operations and can be performed even manually. When calculating a sufficiently large network, we recommend creating in MS Excel (or other convenient application) a plate with calculations of all components for each optical circuit.

To further expand the PON network in optical splitters located between clusters, it is recommended to leave free ports - the so-called "growth points". The problem is how to choose the percentage of power allocated to this backup port.

If the project determines the number of network users at subsequent development stages, the percentage of capacity is calculated in the same way as in the example above. If the next stages of development by the terms and subscribers are viewed vaguely enough, it is easier to do without growth points at all. The problem of PON expansion can be solved by replacing the splitter or using a CWDM multiplexer, connecting a new network segment at a different wavelength.

## Application A

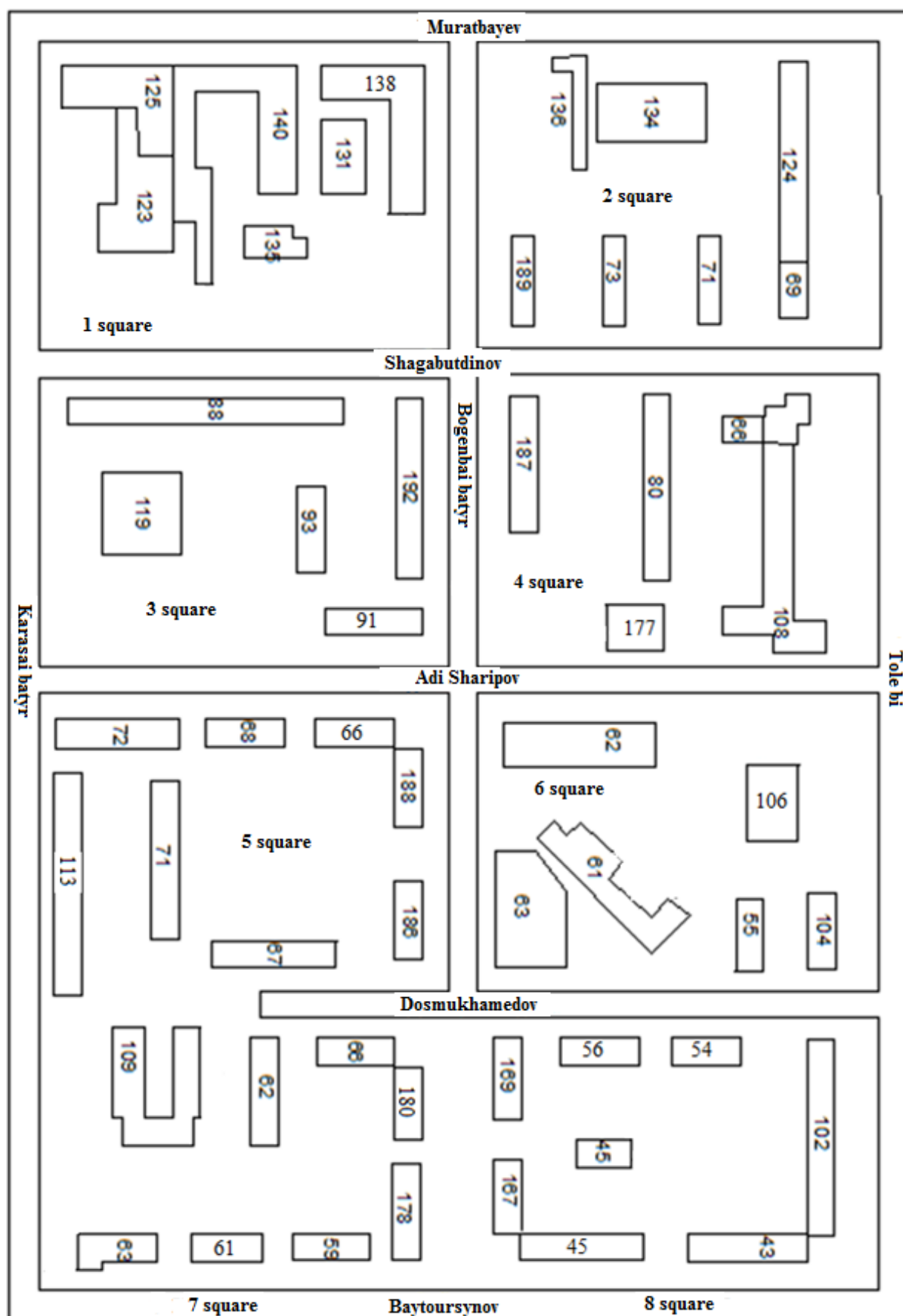


Figure A.1 – Section №1

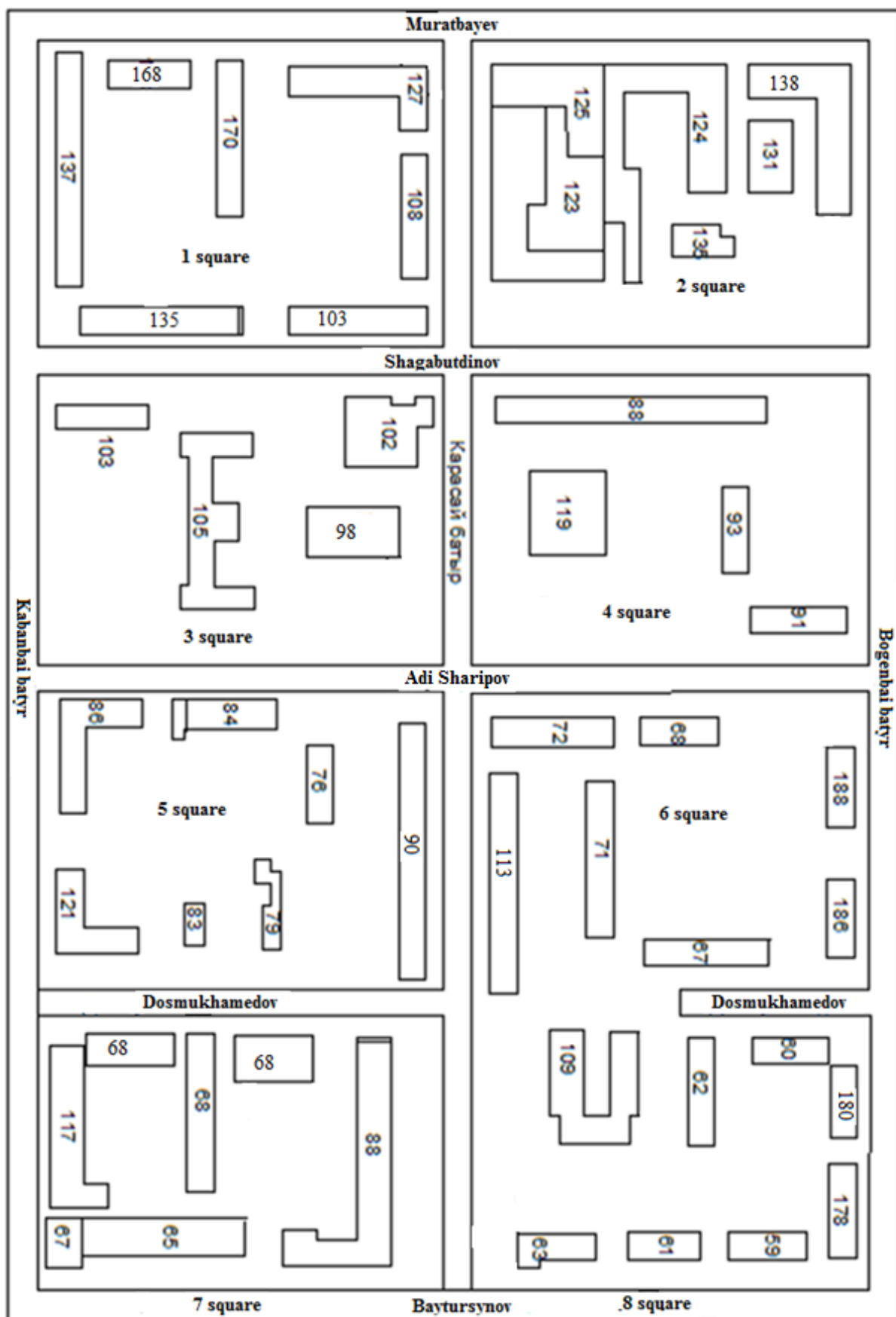


Figure A.2 – Section №2

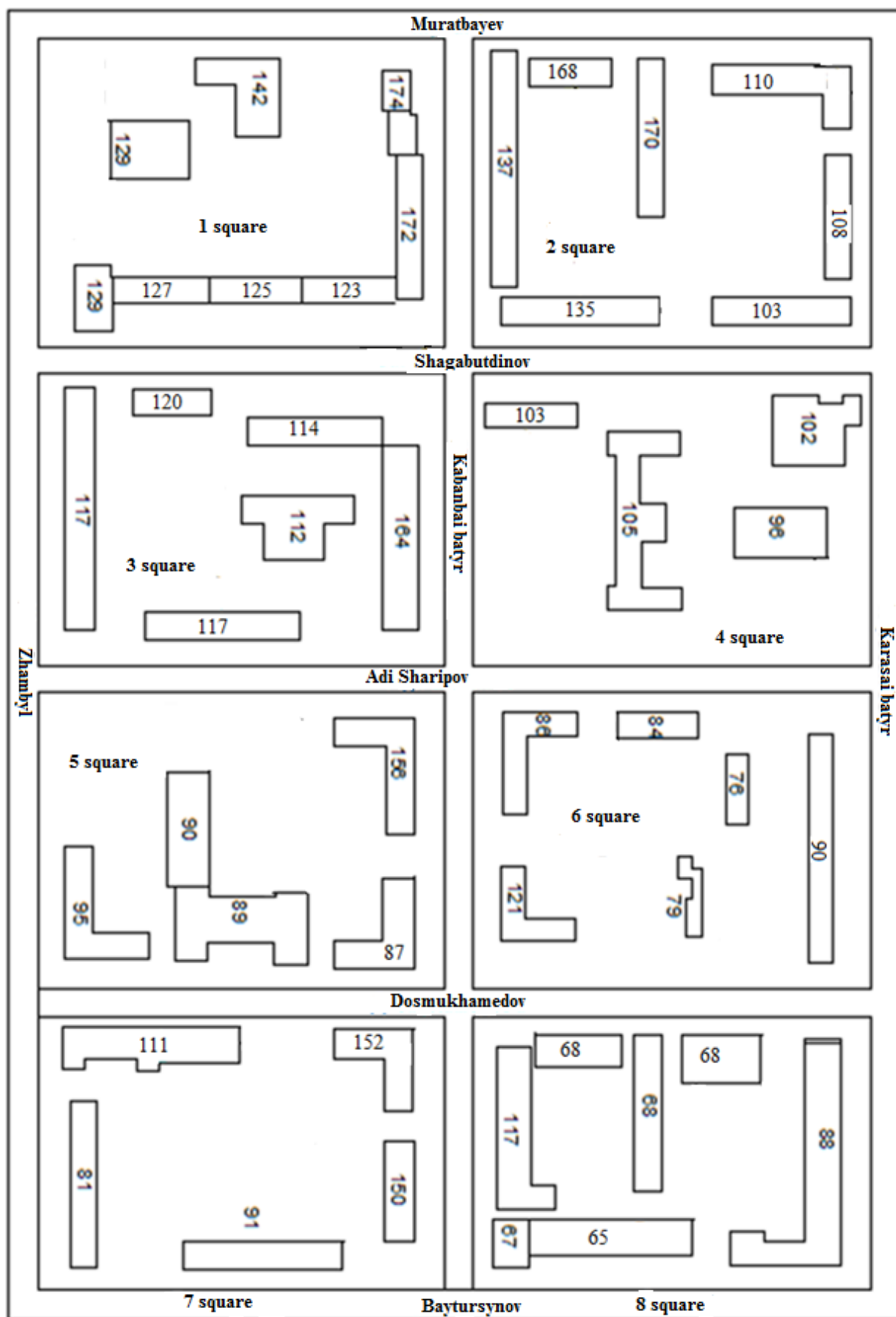


Figure A.3 – Section №3

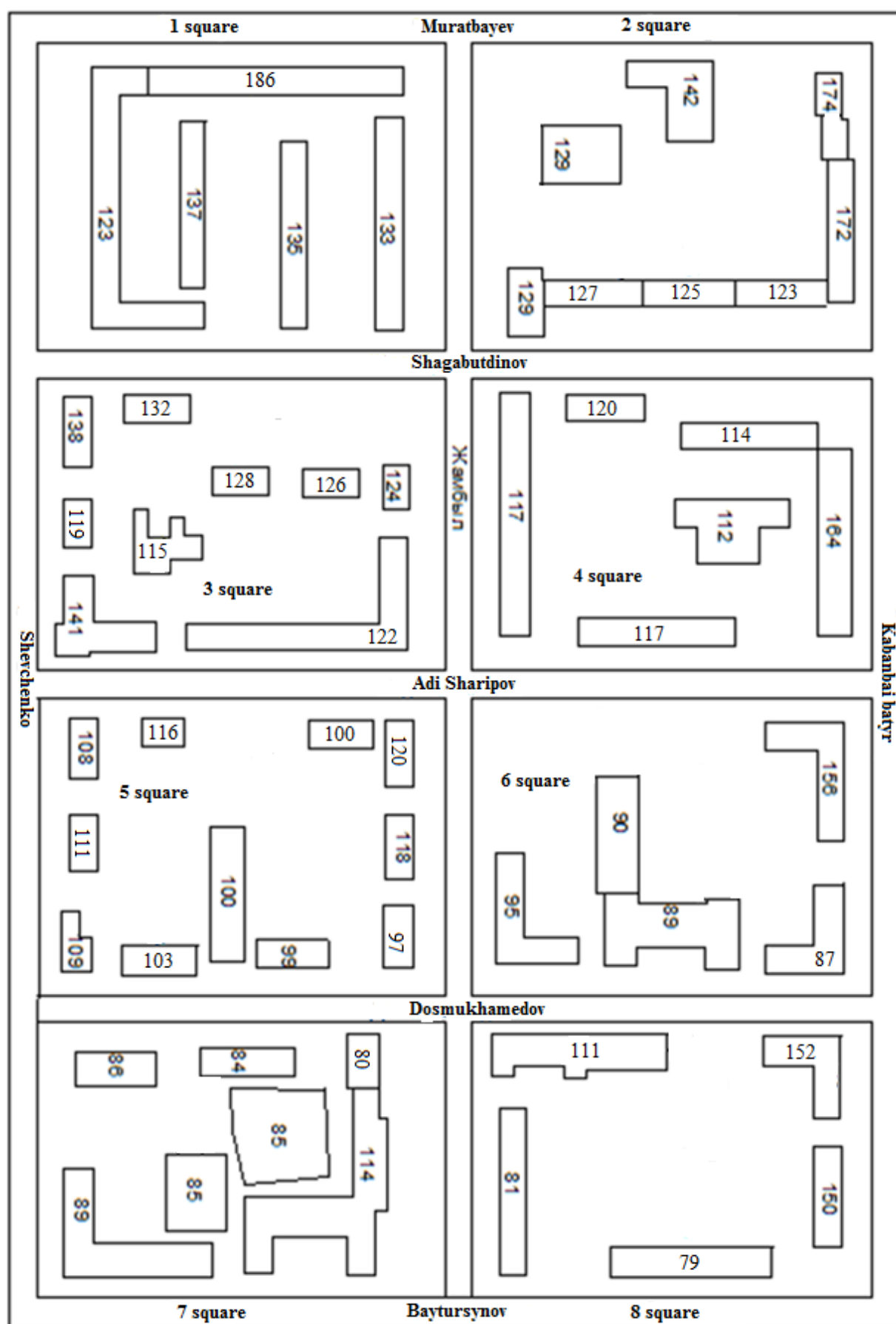


Figure A.4 – Section №4

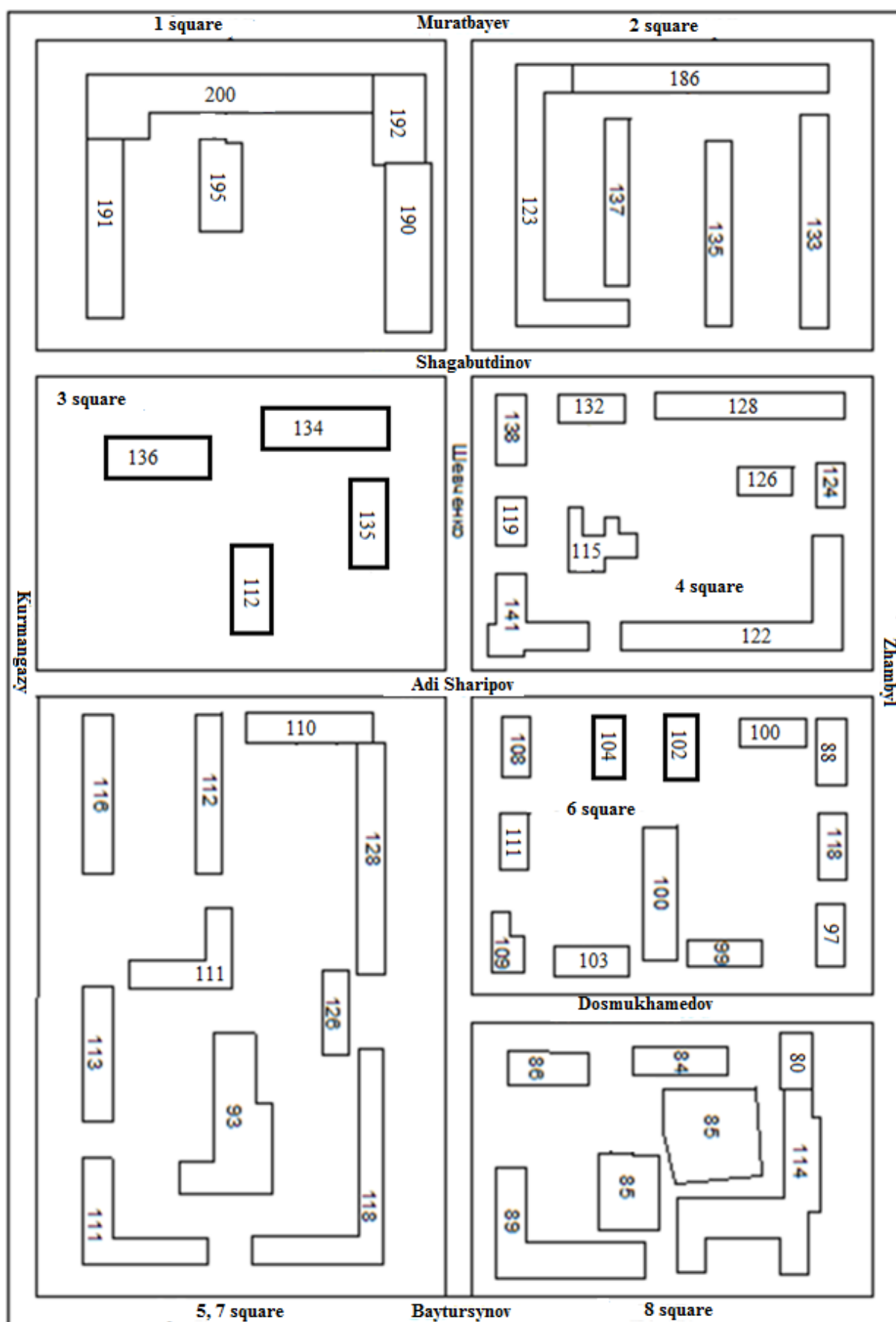


Figure A.5 – Section №5

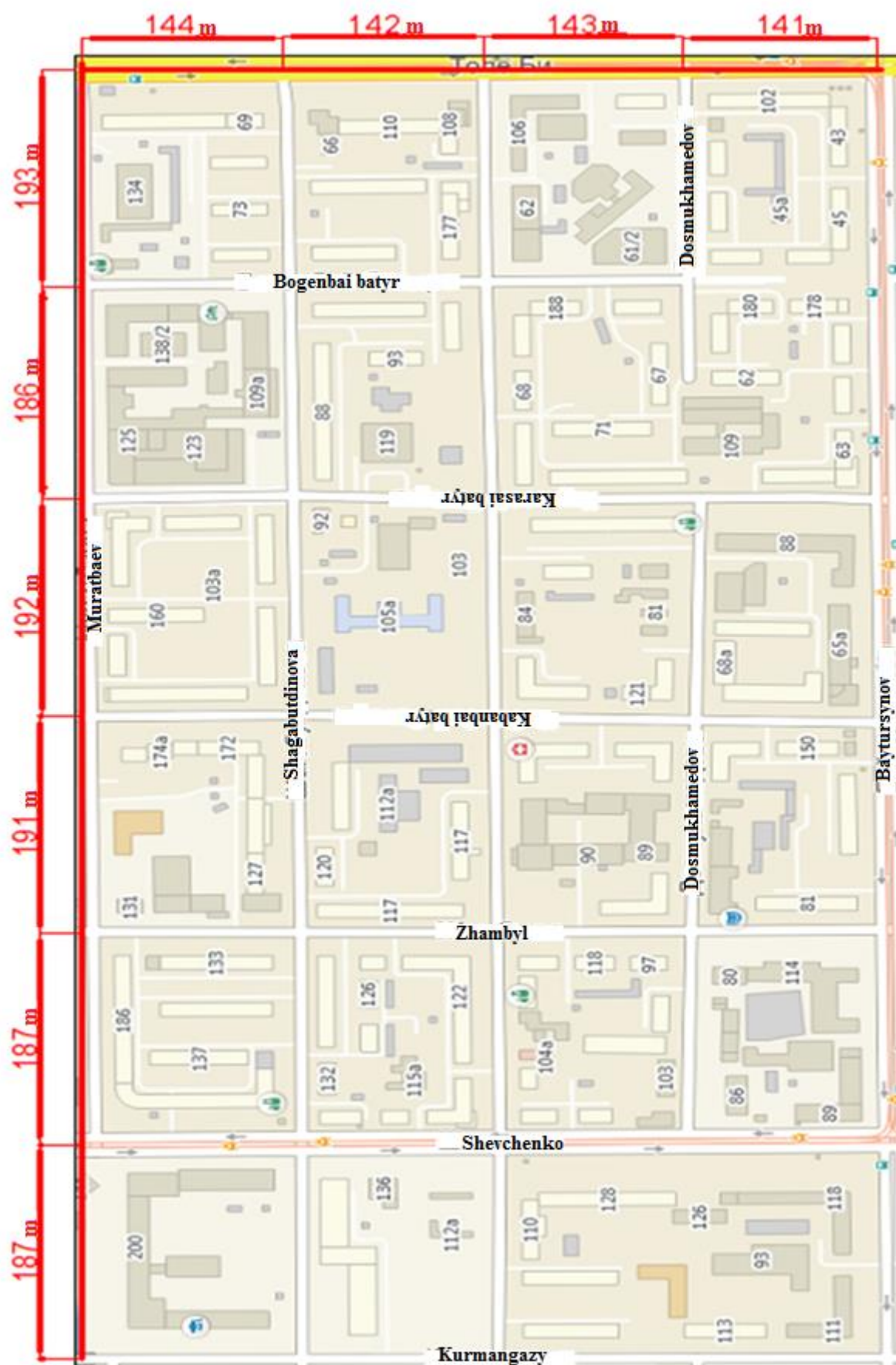


Figure A.6 – General map of the projected area



## Application B

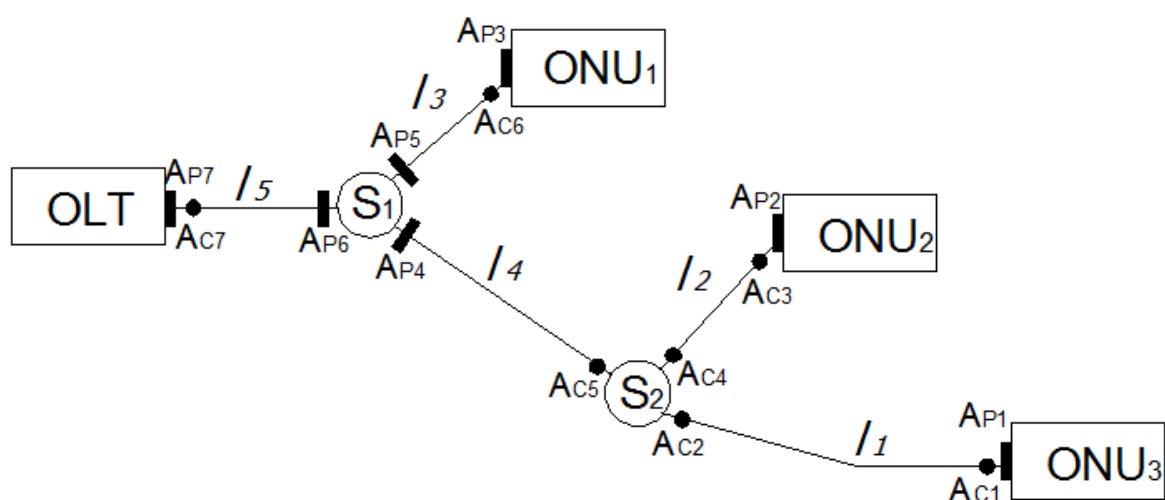


Figure B.1 – Section №1

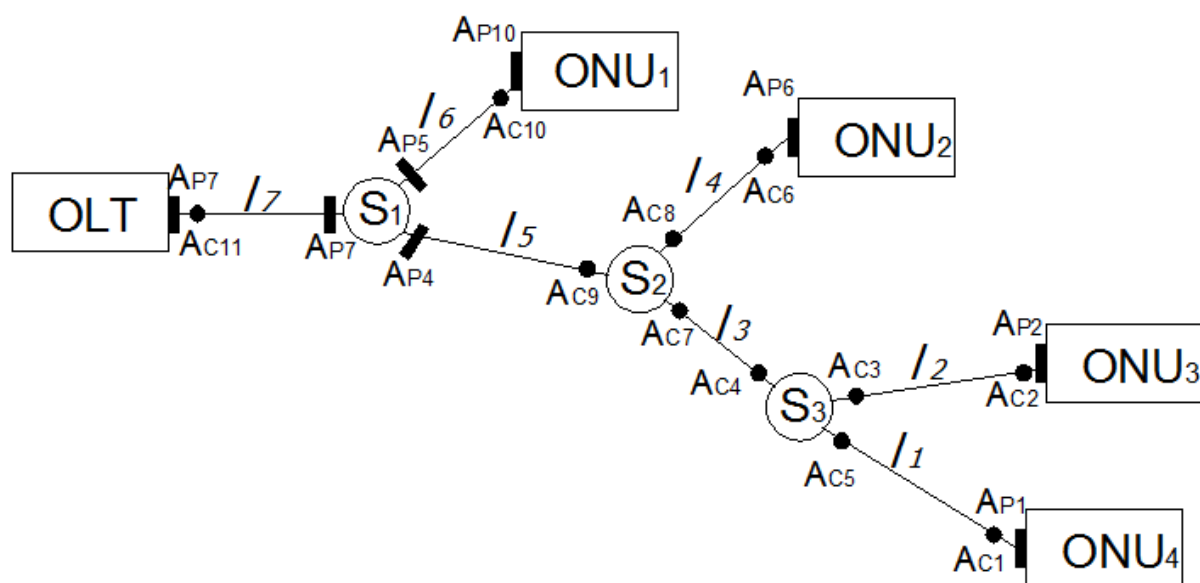


Figure B.2 – Section №2

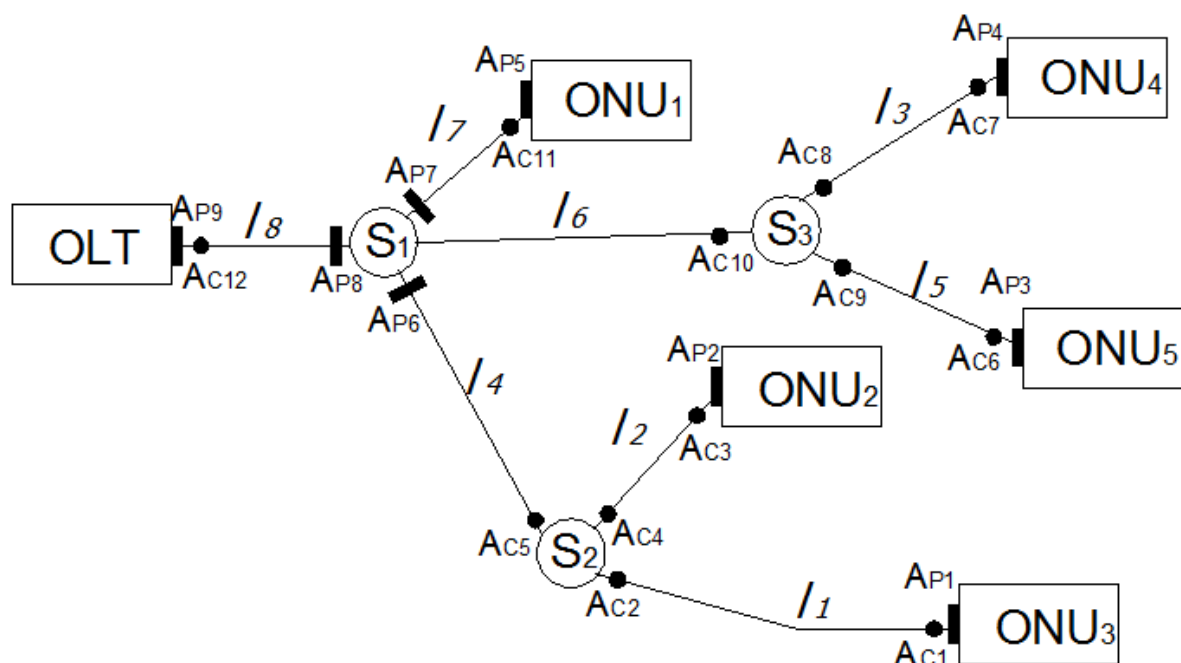


Figure B.3 – Section №3

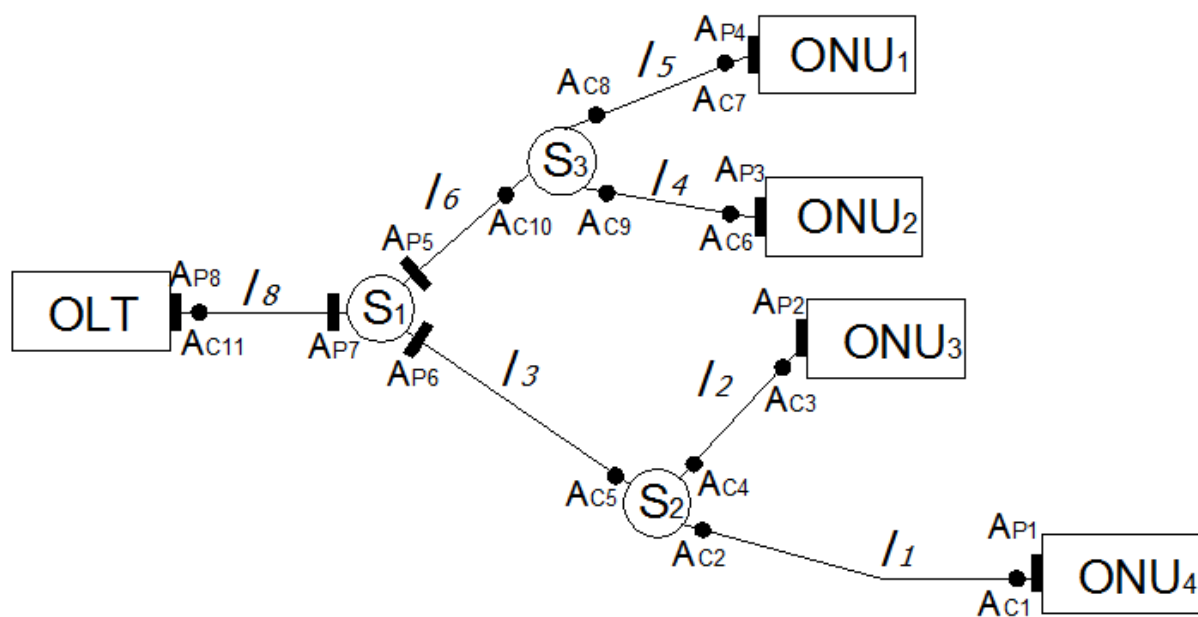


Figure B.4 – Section №4

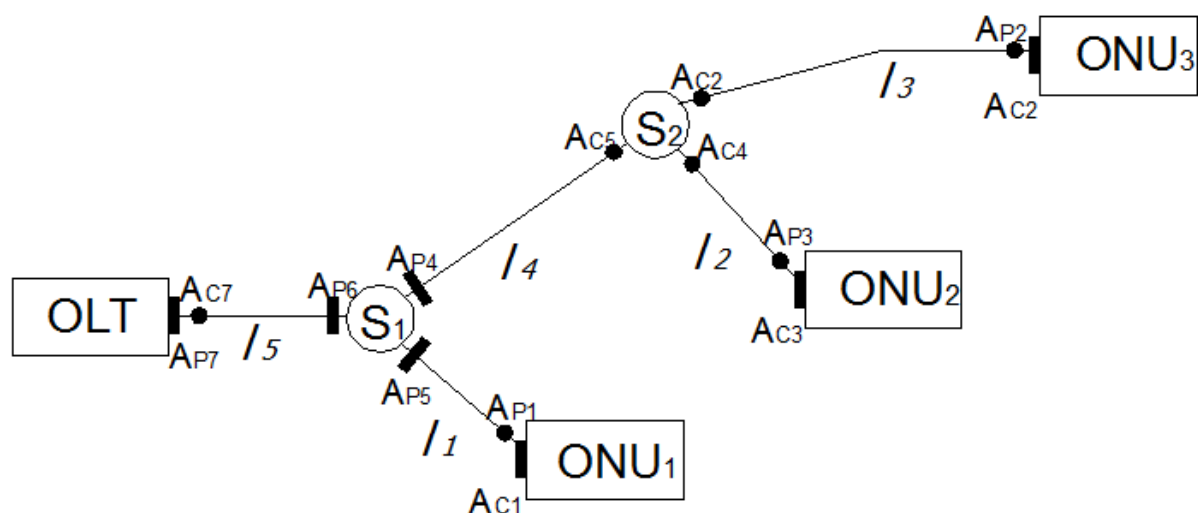


Figure B.5 – Section №5

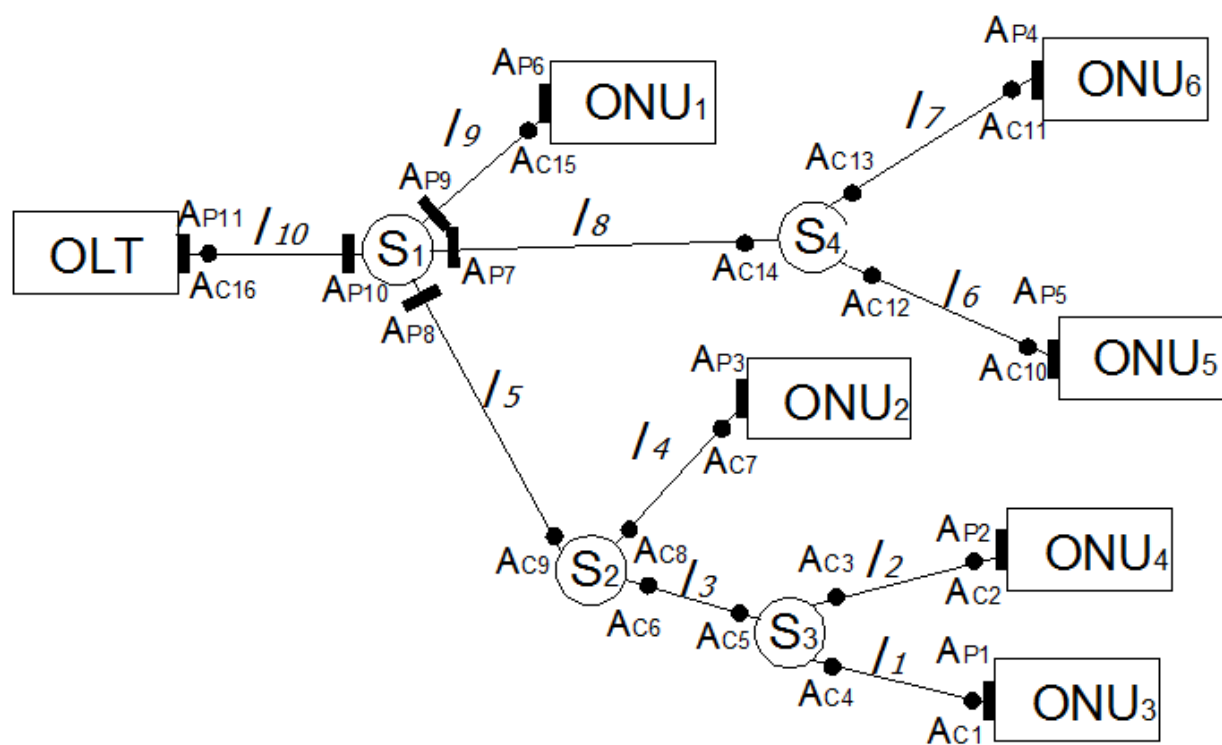


Figure B.6 – Section №6

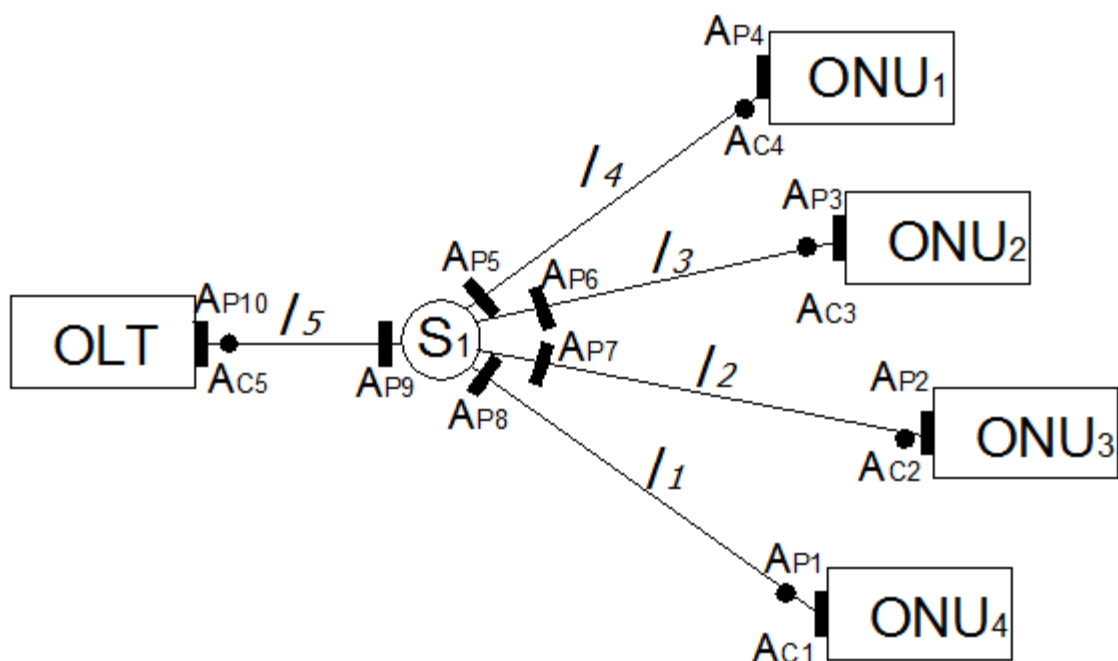


Figure B.7 – Section №7

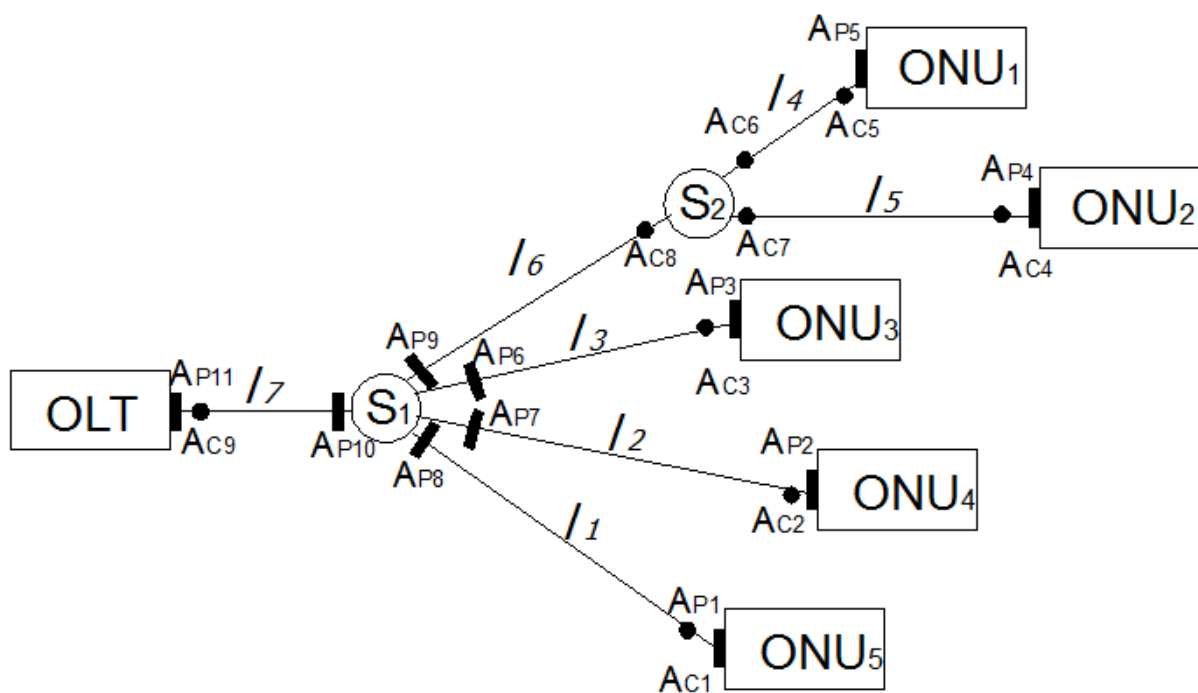


Figure B.8 – Section №8

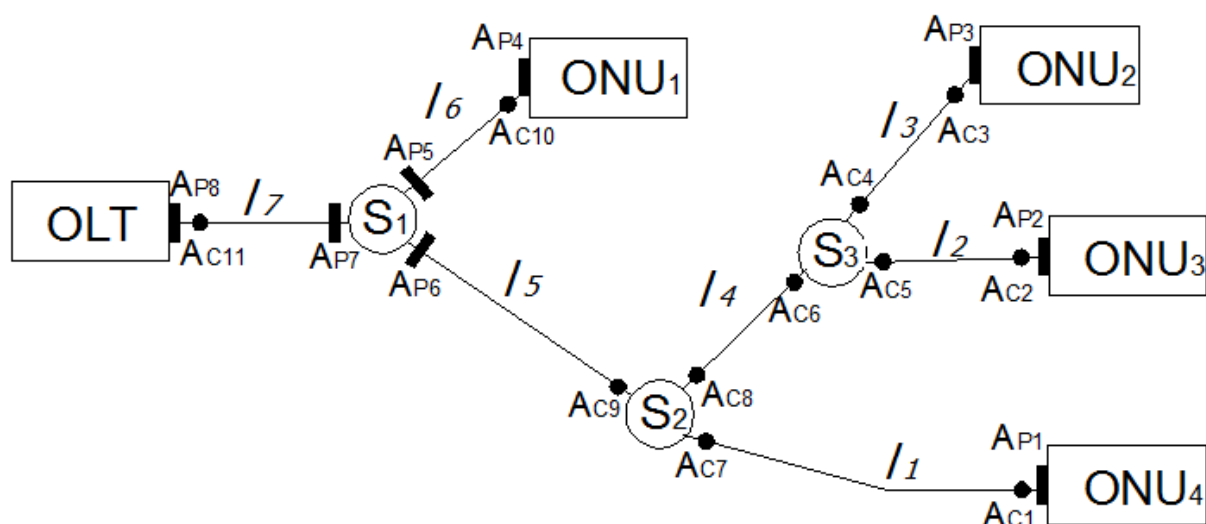


Figure B.9 – Section №9

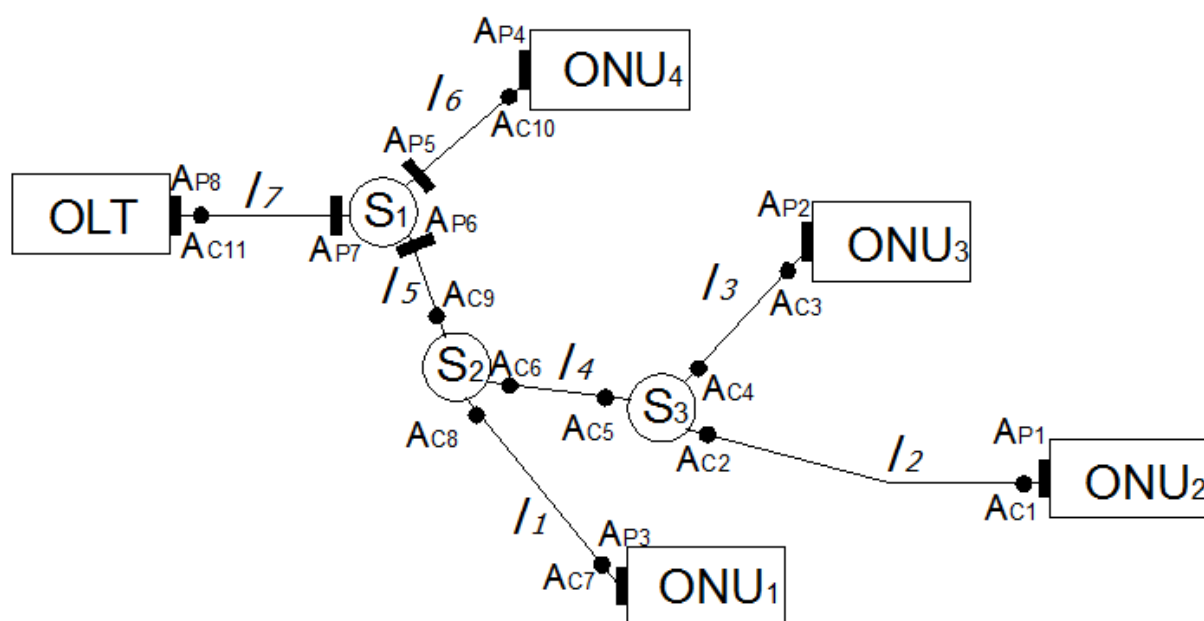


Figure D.10 – Section №10

## Bibliography

- 1 Fokin, V.G. Optical transmission systems and transport networks: Textbook for universities / VG Fokin .- M.: ECOTRENDS, 2008
- 2 Grachev, A.F., Chernyshevskaya Ye.I., Pustova G.N. Graduation qualification work: Methodical instructions. - Novosibirsk, 1999.
- 3 Ivanov, A.B. Fiber optics: components, transmission systems, measurements. - Moscow: CYRUS SYSTEMS Company, 1999.
- 4 Kokh, R., Yanovsky, G. Evolution and Convergence in Telecommunications. - M.: Radio i svyaz. 2001.
- 5 Sklyarov, O.K. Fiber-optic networks and communication systems. - M.: SOLON-Press, 2004.
- 6 Sterling Donald J. Technical manual on fiber optics. - M.: Publishing house "LORI", 2001.

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