Heterogeneous Multiprotocol Vehicle Controls Systems in Cloud Computing Environment

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Abstract: The paper introduces a heterogeneous multiprotocol cloud computing environment for vehicle monitoring and applicable services. It also highlights the concept behind virtual vehicle communication with multi-protocol data access. Cloud based vehicle servicers require constant access to the Internet, which can be organized using a combination of local (Wi-Fi, DSRC) and the wireless communication technologies. The paper discusses the advantages of multi-protocol communication with the possibilities of alternative ways of delivering messages between vehicle and a cloud. The paper presents simulation of different scenarios with respect to the technology used.

1 INTRODUCTION

With the emergence of cloud computing many existing vehicular applications may be enhanced along new functional dimensions, including online access to high performance computing algorithms and practically unlimited data storage resources. Cloud services are now being considered as a source of various innovations in the information and management spheres which can further empower existing Vehicle Controls Systems (VCS). These new services would need to be in accordance with performance and security requirements of future intelligent control systems. Expanding the range of these services leads to an increase in the volume and/or value of data that flows between vehicles and creates new content for automotive protocols. Objects and subjects of cloud services can be divided into three main categories: 1) communication infrastructures which support active safety features in avoiding accidents and traffic congestions 2) elastic access systems shared with high performance data processing, monitoring and channel integration services 3) ubiquitous storage systems to store data sessions and archive traffic and vehicle information. The applications of such cloud services can be utilized by various industries and parties including automakers' analytic centres, drivers, passengers, emergency departments, vehicle owners, regional traffic centres, dealerships, and road services. Operative interaction between users and information resources forms scalable frameworks for:

- Monitoring the technical condition of vehicles;
- Traffic control and emergency assistance
- Insurance settlements with customers;
- In-vehicle entertainment;
- Solutions for intelligent transportation systems.

In the existing VCS, most operations use resources of embedded computing. An alternative approach is to perform some non-safety critical operations remotely while exchanging information with the vehicle using on-board wireless communications appliances. Although the idea of transferring some of the computational tasks to a remote server is straightforward (see figure 1); its technical implementation is challenging and so far has been focused mainly on infotainment applications. In this paper we propose a multi-communication protocol solution that can facilitate intelligent computation of the data exchanged between the vehicle and the infrastructure and vice versa. This solution shall eliminate some of the current existing complexities accompanied by the single protocol approach.

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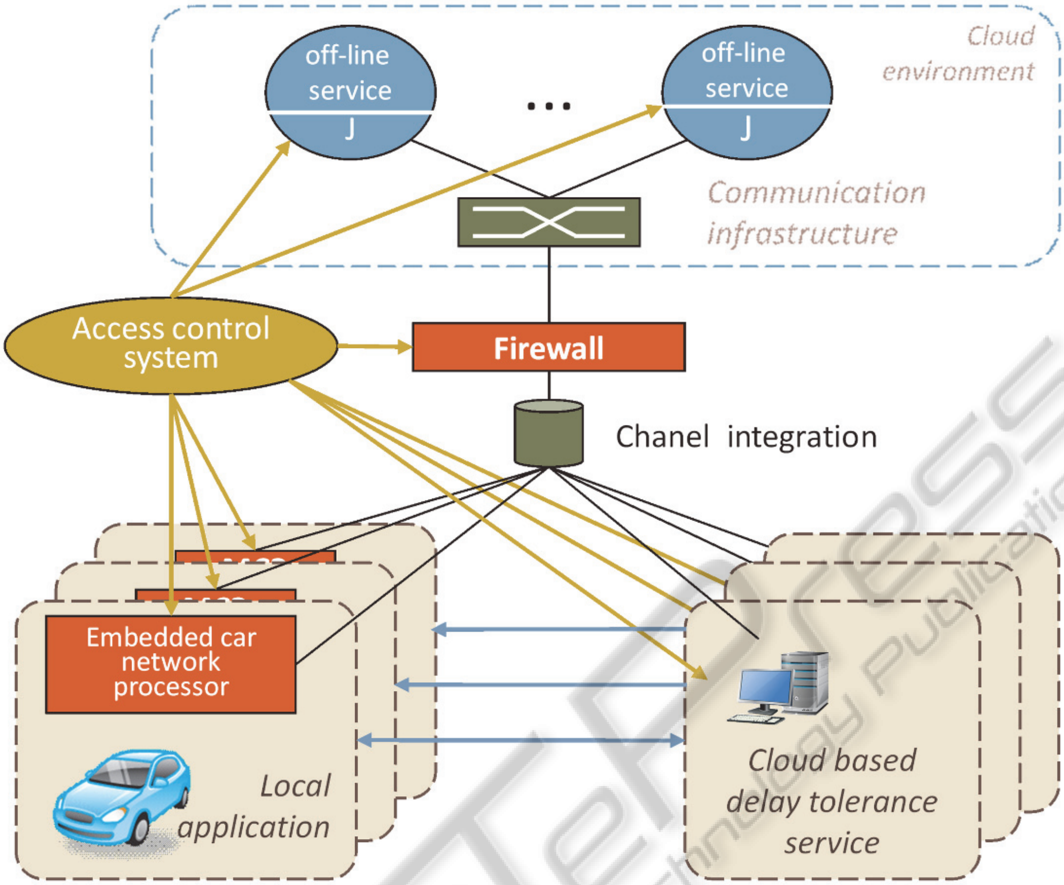

Figure 1: Basic cloud environment running local and remote service.

Each vehicle is treated as a source of information to the cloud environment and to other vehicles simultaneously. The vehicle control system itself shall have a non-zero probability to crash or fail. However, the flow of data from vehicle via wireless mediums is susceptible to interference that can disrupt connectivity and interaction of network nodes and service components. In this case, the reasonable metric of effectiveness of the tasks listed above is the probability of delivering the message in a given time interval from the source to a particular destination within the shared cloud infrastructure. Delivery probability is a controlled parameter which is a function of the cloud resources needed to process requests for services. For example, fault tolerant implementation of supervisory tasks, such as route planning or vehicle speed set-point can be achieved with requested level of probability relying on the distributed cloud computing power. Furthermore, service agents which interact with vehicle applications and run on a remote virtual machine (VM) can improve or even optimize vehicle performance by analyzing historical driving patterns along the same route over many different conditions. Cloud based approaches allow the extension of the existing vehicle on-board resources by taking advantage of collaborative services. However, the probabilistic nature as well as latency in delivering urgent information can delay the delivery of safety critical applications running over shared cloud resources. Today, not all vehicles are equipped with wireless access appliances and the wireless network coverage is not optimum for various wireless technologies. To overcome this obstacle we introduce the concept of a heterogeneous multiprotocol cloud computing environment which integrates different architectures of MESH networks, DSRC, and LTE. Adaptive capabilities of such infrastructure are formed by the use of resources and protocols that under specific circumstances can increase the probability of timely delivery of information necessary for control purposes using different communication media, for example, embedded vehicle's controllers equipped with Wi-Fi, and LTE interfaces.

2 HETEROGENEOUS CLOUD COMPUTING CONCEPT

The use of different communication mediums and protocols which deliver data from the vehicle to the cloud services and vice versa can improve traffic safety and route planning only if we can expand the functionality of embedded computing systems by using the concept of multi-protocol access gateway between vehicle and distributed network resources. In this case each vehicle in the cloud environment can be viewed as virtual agent (Gusikhin, 2011). This virtual agent, that we will call virtual vehicle (VV) encapsulates an information trail on the data being processed by a vehicle. VV is an active agent of information relations which holds information about the current resources and local properties of the vehicle environment. In heterogeneous cloud environments VV may play a role of active data source which contains essential static (do not changes during control operations) and dynamic parameters (environment conditions, GPS coordinates, supervisory commands, fuel consumption, or control signals, etc), information about vehicle motion and/or driver behavior (Zaborovsky, 2011) (Mulukha, 2011). VV is a logical node in MESH segments and a virtual resource on IaaS level which combines actual vehicle' data with wealth of information available from computational and storage resources. The programmable and multiservice nature of VV provides a wide variety of opportunities to realize intelligent control algorithms and merge together different models of vehicle motion with global data and goal oriented forecasts in which VV is represented as an intelligent agent of heterogeneous the cloud/MESH environment. VV may be viewed as a subject of appropriate control decisions which are based on ubiquitous high performance cloud computing platform ("hpcc-platform") and storage resources that are available as a service. Once a vehicle has been driven on the road, its VV image becomes a part of cloud-based services which monitors the vehicle during all control sessions. There are several advantages behind such a heterogeneous architecture. High-computational and communication power associated with the cloud environment is a major source that can significantly extend the operational and optimization capabilities of a new generation of VCS. Cloud-centric VCS form composite decisions based on the fusion of different factors including vehicle dynamics, specific constraints, on-line information from road sensors about surrounding moving and non-moving objects. All VCS operations such as routing or vehicle parameters optimization may be done at different performance rates. This rate can be accelerated by reconfigurable (Msadaa, 2010) available virtual and computing resources in accordance with vehicle speed.

The concept of virtual machine in the heterogeneous environment of the cloud architecture, that we are proposing, provides the implementation of fault-tolerant, powerful and flexible tool for managing the traffic services, roads infrastructure, and vehicle data. The implementation of such concept which is based on the organization of access to cloud services is executed through the currently existing wireless and hard-wire connections of the various technologies. Those connections can be placed on vehicles, on objects of road's infrastructure and services providers. That leads to simultaneous use of communication channels of various technologies for improved accessibility to cloud services which requires integration to the shared wireless multiprotocol network of data communication.

3 MULTIPROTOCOL COMMUNICATIONS

To fully leverage cloud-based infrastructure in providing different vehicle services, especially within mission critical tasks we need to ensure a fault tolerant communication infrastructure with a given probability of message delivery within a given time interval. The lack of a stable 2G/3G/4G coverage in the highways and transportation infrastructure along with the impracticality to equip each vehicle with an access device to the local and global networks leads to the need of developing alternative methods of data communication with the cloud.

The model proposed in this paper is centred around using existing industry standards represented by mesh networks, Wi-Fi (802.11), DSRC and LTE (Yoon, 2010) (Navarro, 2007) technology. However, in practice, the implementation of this approach faces a number of challenges:

- Incompatibility of network equipment;
- High costs of implementation of new technologies;
- Difficulty to ensuring reliability in case of high message rate.

The first problem can be solved by using network access devices with reconfigurable multifrequency radio interfaces that are at the software level compatible with the protocols of global and local wireless networks.

To support processing of information interactions mentioned above requires designing a new generation of multi-protocol routers for DSRC, LTE, MESH, WI-FI networks. Such routers should synthesize optimal paths taking into account the nominal and available bandwidth as well as ongoing delays of delivering data packets or control information. These routers should have a well-defined relationship between: 1) data rate and the available virtual channel bandwidth, 2) routing policy and the current network topology, and 3) routing algorithms and the data characteristics type the characteristics of the data link layer protocols. The basis of these routers are the multi-core multi-threaded network processors whose functionality are extended through the use of FPGA co-processors which provide high-performance internal operations for multi-band processing of the incoming traffic.

The solution for the second problem can be done by using the method of "seamless" roaming between Wi-Fi, 2G/3G/4G, which are based on technology Hotpsot 2.0 (Next Generation Hotspot - NGH). NGH technology provides an authentication procedure and handover, as well as support for automatic logon of mobile devices to the network without the need for re-authorization (Heller, 2006) (Andreev, 2010).

The effect of the third problem can be mitigated by using recommendations from 802.11 x protocol suite that allows creating Wi-Fi network that supports alternative data routes. Development of mesh Wi-Fi infrastructure based on the 802.1x specification provides self-organization of networks and increases the ability of networking recovery in case of failure of the switching nodes.

IEEE 802.11v specification provides support mechanisms for controlling the radio parameters in order to reduce energy consumption which is important to support self-contained modules that are unable to regularly recharge (for example, in the vehicle). The promising solution that can improve communication sessions for short-range areas is to use 60 GHz frequency band with peak data rates up to 7 Gbit/s in accordance with the recommendations of Wireless Gigabit Alliance (Arbabi, 2010).

A common solution to these problems is to create a multi-protocol access point (MPAP) which helps to raise the reliability of message transmission in areas with low density of network stations or difficult terrain. From the technical point of view, MPAP is a modular hardware and software system that supports concurrent messaging technology and robust routing algorithms. Functional requirements of the MPAP are the follows:

1. Connecting to the vehicle.
2. Connecting vehicle to the wireless data networks.
3. Relaying messages between networks of different technologies.
4. Sustained interaction with the objects of road infrastructure.
5. Effective interaction with providers of data networks.

Figure 2 shows the block diagram of MPAP. Currently, stationary transmitters of road infrastructure and vehicle messages regarding road conditions, which inform drivers and embedded controllers about the state of traffic lights, signs, specific facts of reducing distances and intervals between vehicles, or the presence of congestion and accidents on the road.

DSRC is an optimum solution to send short messages between vehicles and emergency infrastructures in a very short period of time. The advantage of technology is the short time connection between the stationary and mobile transmitters, high speed data transfer and the maintenance of a stable connection with vehicles moving at high speeds.

The use of DSRC technology in the network of stationary and mobile devices allows creating effective message delivery system for cloud services. In this case, the DSRC technology is implemented at the transport layer and controls delivery of high-priority messages that are generated as a result of the integrated emergency call system.

These messages transmitted not only via dedicated channel associated with the specific emergency network but also using LTE or 3G wireless networks (Gramaglia, 2011). Simultaneous and parallel transmission of emergency messages using different protocols and two independent network infrastructures can significantly reduce the time and increase the likelihood of message delivery to the specified address.

4 SIMULATION EXPERIMENT

A study of the possibility of delivery of emergency messages from the vehicle to vehicle with an output interface to the cloud computing environment by means of LTE channels was also conducted in this paper.

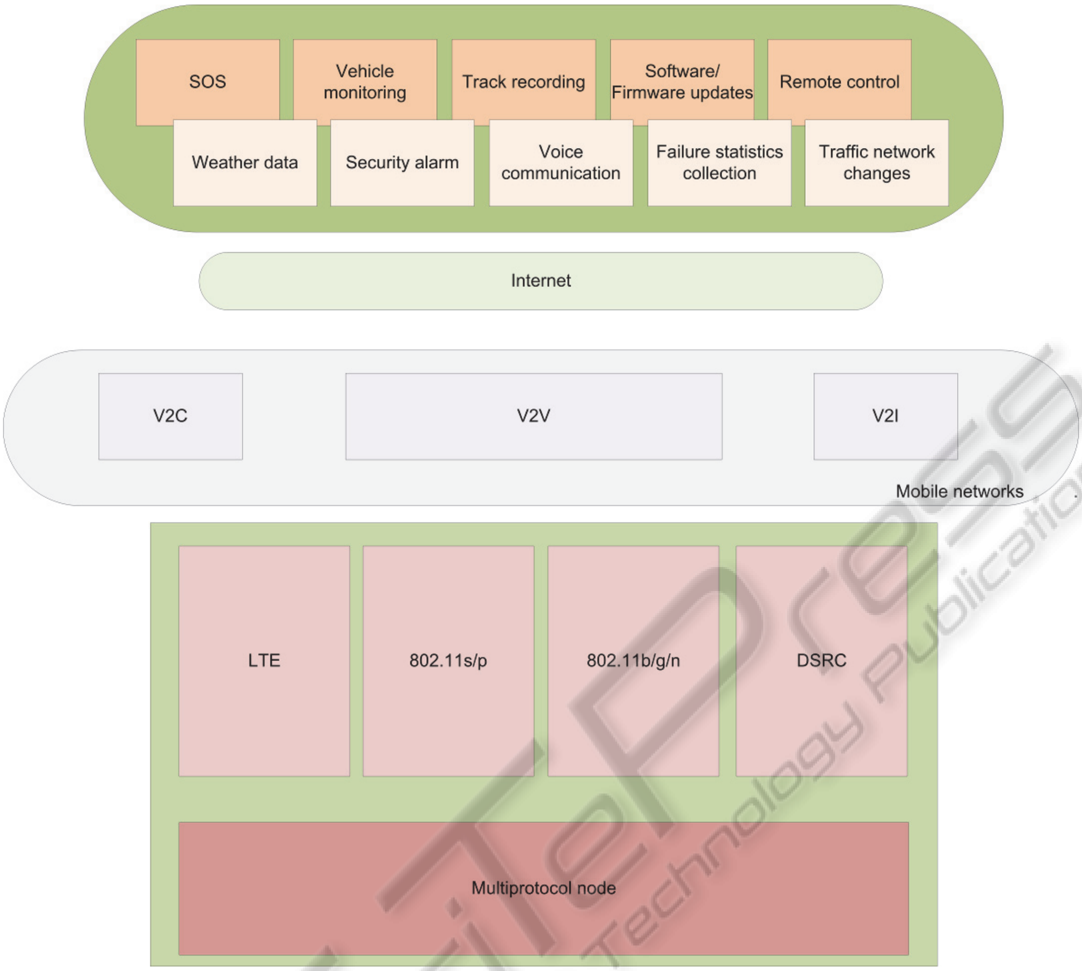

Figure 2: The block diagram of MPAP.

The first experiment consists of fragmenting an 800 meters road that contains 4 turns at 90 degrees. The road has 4 lanes broken down by 2 on each side, on the fragment of the road there are always 8 or 16 vehicles (1 or 2 vehicle for every 100 meters) equipped with 802.11s (number of vehicles leaving the fragment is equal to the number of road vehicles that fall in this fragment of the road) - one half of the total number of vehicles are moving in one direction and the other half of the vehicles are moving in the opposite direction. Traffic is moving according to the IDM model with the following parameters: maximum speed of 10 to 100 miles/hr - varied in increments of 10 miles/h (parameter of the experiment), the distance between any two vehicles is at least 4 m, the acceleration of 5 m/s^2. One vehicle is equipped with a dedicated LTE modem. The simulation also included one vehicle that transmits emergency messages to the infrastructure and the other vehicles via the mesh network. The experiment evaluated the percentage of delivered emergency messages.

Figure 3. shows a graphical representation for the results obtained from simulating the mesh network under different conditions. The results of the experiments with MESH network using NS3 simulator (Yoon, 2010) (Heller, 2006) which is based on 802.11s shows clear relationship between vehicle speed and the distance between vehicles and the total loss rate (Fig. 3).

Analysis of the data presented in Figure 4 shows that at speed of 100 miles per hour and traffic density of 1 or 2 vehicles on a road segment of length of 100 meters a loss percentage of 78-92%. It can be concluded that in such condition of movement it is necessary to increase the density of vehicles that are equipped with on-board 802.11s transmitter or to create alternative ways of delivering emergency messages.

In the second experiment we consider the same simulation parameters: four-lane road and traffic model with 16 vehicles available on the road.

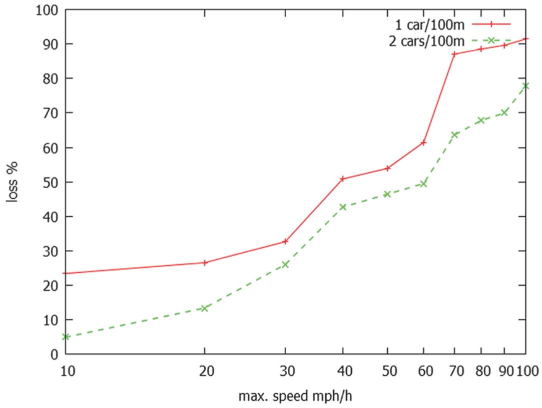

Figure 3: The dependence of the loss rate to deliver a message from the emergency vehicle.

Among these vehicles there are vehicles equipped with output interface to the cloud by means of LTE. The percentage of vehicles equipped with LTE modules is 3-25% (the parameter of the experiment). In case of accident the vehicle initiates the transmission of emergency messages addressed to: any vehicle equipped with output interface to the cloud, using transport mesh (802.11s). The experiment evaluated the percentage of delivered emergency messages.

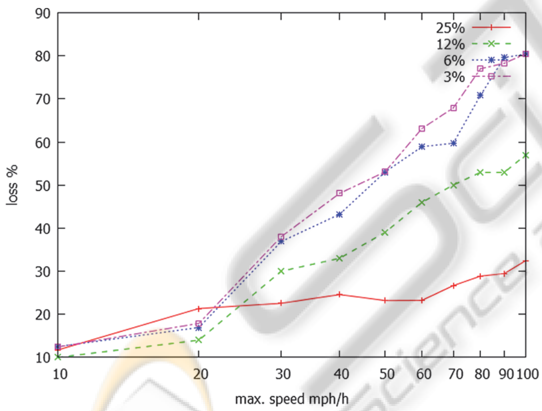

Figure 4: The dependence of the messages delivered from vehicle speed and their concentration.

Figure 4 shows the percentage of messages loss at a rate of 2 vehicles a 100 meter long road when the vehicles equipped with 802.11s transmitter and the share of vehicles equipped with LTE modules is the following: 25%, 12%, 6%, 3%.

Analysis of the obtained dependency leads to the conclusion that the use of protocols for mesh networking (802.11s) increases the reliability of message delivery to nodes equipped with output LTE interface to the multiservice cloud computing environment. The number of the vehicles with such interfaces should be at least 25%. Otherwise, more than 50% of sent messages may be lost. It is advisable to use a reconfigurable data transmission routing platform which is capable of finding an alternative path for messages and reach the cloud via DSRC, Wi-Fi, or even others network infrastructure.

The third experiment illustrates the alternation between the different protocols controlled by the bandwidth variances. The operation of combined mobile vehicles networks equipped with multiprotocol device with two interfaces: LTE and 802.11p. In case of low LTE bandwidth usage, the majority of messages are transmitting over LTE. While when the LTE network is overloaded, the high-priority emergency short messages are transmitted over 802.11p channel as an alternative way. This situation shows how a multiprotocol node increases the ability of transferring messages using 802.11p channels at moments of peak loads on LTE network.

This experiment consists of fragmenting an 800 meters road that contains 4 turns at 90 degrees. The road has 4 lanes broken down by 2 on each side, on the fragment of the road there are always 16 vehicles (8 vehicles on each direction). Each vehicle is equipped with LTE and 802.11p interfaces. On the roadside there is 802.11p-receiver working as a repeater. Main goal of experiment is to check the ability to transmit short (1 KByte) emergency messages from moving vehicles through 802.11p transceiver to 802.11p access point. Transmission speed of every node is changing from 8 Kbit/s to 256 Kbit/s. 802.11p network load is measured using TCP and UDP transport layer protocols (figure 5).

The dependency shows that network utilization reaches critical value at 256 Kbit/s transfer speed, wherein UDP protocol shows 25 percent less network utilization compared to TCP. It is worth

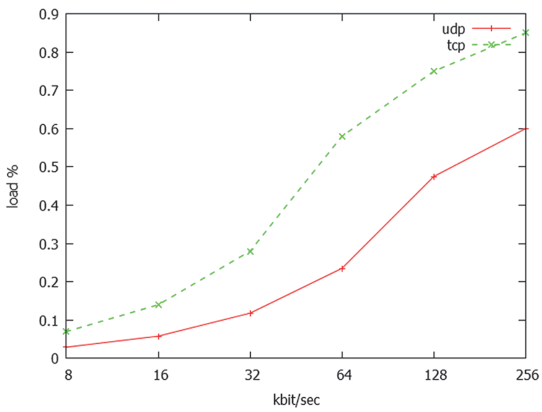

Figure 5: Dependency between 802.11p network load and messages transmission speed.

noting that the amount of undelivered messages reaches 40 percent at 256 kbps transfer speed (based on transport layer protocols statistics data of this experiment). At transfer speeds of 128 Kbit/s or less the amount of undelivered messages is insignificant; messages are delivered up to 40 percent faster (in average) over UDP compared to TCP.

Thus the multiprotocol interface improves network characteristics in case of overloads at main data transfer channels and in case of critical network operation modes.

5 CONCLUSIONS

Current trends in information services establish new challenges for developers of network protocols and equipment. Promising areas include:

– the development of universal reconfigurable wireless devices that adapt to the specifications of multi-protocol network nodes to ensure compatibility standards for the transmission of data in local and wide area networks;

– the use of multi-protocol services, grouped under an hpcc-platform that provides rapid reconfiguration of virtual computing resources with a goal to increasing the productivity of cloud applications and the probability of delivery of urgent messages;

– development of methods to increase the probability of emergency message delivery in areas with unstable coverage zones. Duplication of priority traffic via public wireless networks;

– new 802.11x standard which can significantly reduce the costs of mobile network development while providing high-speed connectivity of mobile devices over short distances and secure access to multimedia services.

– the use of alternative channels of communication such as DSRC, leads to the increased quality of communication at the moment of message transmission when other channels such as LTE and 802.11s are unavailable. It follows that along the road transceivers can be located providing a stable zone of coverage.

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