The proposed project deals with Logical Tunnel Capacity Control (LTCC) – a novel concept of a traffic routing and protection strategy applicable to communication networks with variable capacity of links. LTCC makes use of logical tunnels, such as MPLS virtual tunnels, i.e., LSP – label switched paths. Each traffic demand is assigned a fixed set of tunnels between its end nodes, whose capacity is dedicated to carry the demand's packet streams. The (virtual) capacity of the tunnels is controlled at their originating nodes through thinning their nominal capacity in order to follow fluctuations of links' capacity

The main research goal of the project consists in elaborating theoretical foundations of the LTCC strategy functioning. This will require solving the following scientific problems:

1. Elaboration and implementation of optimization models together with efficient resolution algorithms for link capacity and logical tunnel flow optimization for networks applying LTCC.
2. Elaboration of a functional model of a network implementation of LTCC based on the MPLS technology, selected protocols from the TCP/IP stack, and selected mechanisms controlling packet admission and assignment to logical tunnels.
3. Elaboration, Implementation and verification of a simulation model of a LTCC network implementation in a selected wireless network architecture, providing a proof of concept of the proposed strategy.

The basic research carried on in the project will first of all deal with the above described Problem 1 since efficient optimization models and algorithms are necessary for traffic effectiveness of LTCC, i.e., for maximization of demands' packet traffic flows realized in the link availability states. Problem 1 is broad and difficult. It requires application of the multicommodity flow network theory to formulate appropriate LTCC optimization tasks, as well as elaboration of advanced specialized linear programming and mixed-integer programming methods and algorithms for their resolution. The main mixed-integer programming approach will be based on the branch-and-price-and-cut framework, i.e., on the branch-and-bound approach adjusted with column generation and cut generation, enhanced with fast stochastic heuristics. The modeling and algorithmic approach will be extended with the method of linear programming called robust optimization, including the use of affine decision rules.

The development of the functional LTCC model in Problem 2 will involve analysis and testing of the selected TCP/IP protocols, as well as selection and tuning of low level QoS packet admission control mechanisms such as leaky bucket and other traffic shaping and traffic policing mechanisms.

Problem 3, in turn, will apply the simulation method.

Traffic routing and protection strategies implemented in the management systems of communication networks are crucial to their traffic handling effectiveness. Clearly, the effectiveness in question should be ensured in all link availability states. This aspect becomes especially profound when wireless transmission is used on network links making their capacity variable, i.e., the case addressed by LTCC.

A particular case of wireless networks where application of LTCC can bring significant benefits are wireless mesh networks (WMN). WMNs are composed of fixed IP routers and Internet gateways, interconnected by wireless links based on the radio, microwave, or free space optical (FSO) technologies. WMNs are becoming an important solution for providing broadband Internet access for fixed and mobile users connected to the routers. The reason is that in many circumstances WMNs are cheaper, faster and simpler to deploy, maintain and operate than their wired counterparts. This is for example the case in areas lacking network infrastructure where WiFi radio based WMNs can provide Internet access to entire communities despite the fact that only few nodes (gateways) have direct access to the Internet. Such WiFi networks employing fixed mesh routers are also considered for the smart city applications. Another example is a corporate WMN deployed in a large city using FSO links, connecting pairs of transceivers in the line-of-sight installed on the roofs of buildings. A major distinctive feature of WMNs (and, for that matter, wireless communications in general) is variable link capacity: the link range and its transmission rate can (and should) be adapted to changing, for example weather-dependent, channel propagation conditions. This is achieved through automatic adjustment of modulation and coding schemes making wireless transmissions fit the current channel state.

To illustrate the key role of wireless communications in voice, video and data transfer today it is sufficient to say that in 2013, the global number of mobile-cellular subscriptions almost reached the World's population, generating an unprecedented growth in communication traffic volume that mounted to almost 3 Exabytes (3 million Terabytes) in 2014, and, according to predictions, will continue to grow exponentially in the coming years. Certainly, this growth concerns, to a significant extent, wireless mesh networks as well.

Thus, importance of the proposed research stems from importance of wireless communications, in particular of WMNs, and from the novel control mechanism of LTCC that directly takes into account fluctuations in the available link capacity – an important intrinsic feature of wireless networks that has not been considered to a satisfactory extent in the current and past proposals for wireless traffic control. Additionally, LTCC provides a generic solution applicable to networks other than WMNs, wherever link capacity fluctuations become important and logical tunnels are implementable.

The overall goal of the proposed project is to develop a comprehensive concept of LTCC, taking both its theoretical and implementation aspects into consideration. Although an indirect mechanism of reacting to link capacity fluctuations is intrinsic to TCP (a basic IP network protocol that controls end-to-end packet flows), its reaction time and efficiency in packet traffic handling under variable wireless link capacity is unclear. Yet, examining this complex issue is not the goal of our project – instead, we focus on a complementary LTCC mechanism (i.e., on controlling capacity of end-to-end logical tunnels dedicated to carry end-to-end aggregated packet flows). Somewhat surprisingly, such potentially simple strategies for increasing traffic efficiency in networks with variable link capacity have not yet attracted due attention of the communications research community, at least to our best knowledge. This gap in research is the main motivation of our project.

It should be emphasized that although the advances in multi-state network optimization related to Problem 1 are substantial, the research results in this area available in the literature are not fit to our purposes for a simple reason – the notion of the state has typically been limited to total failures (when a link fails then its entire capacity is lost), and for that matter mostly to single link failures (all the network links can fail but only one at a time) and very seldom to multiple link failures. Clearly, such an assumption is not adequate for modeling wireless networks in their everyday operation as considered by LTCC, i.e., assuming multiple partial link failure scenarios. Another reason of limited practicability of the previous research is that it has been mostly focused on traffic routing and protection strategies that are not applicable to multiple partial failures. To the best of our knowledge, only the so called global rerouting (GR) has been studied in the partial multiple failure context. GR restores the demand's traffic by establishing their flows from scratch in the surviving capacity without any restrictions (contrary to LTCC where given nominal flows can only be thinned). Because of that, GR is the most cost effective traffic rerouting strategy we can think of, but at the same time it is quite impractical in the context of our project, due to excessive end-to-end flow rerouting in case of failure.

The concept of LTCC is novel, as so far there are seemingly no practical, implementable proposals of traffic routing strategies based on logical tunnels, capable of reacting to fluctuations of links' capacity while assuring the assumed levels of traffic carried. Moreover, the theoretical results of the project, that is novel advanced models and algorithms for multicommodity flow network optimization, will present an original contribution to the research field of Operations Research.