Transitions on Multiple Layers for Scalable, Energy-Efficient and Robust Wireless Video Streaming

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***Abstract*—This work demonstrates the effects of multi-layer adaptivity for a wireless live video streaming scenario. We investigate a specific type of adaptations, the so-called transitions, which switch between different network mechanisms during the runtime of an application. In comparison to a pure configuration adaptation, a transition is beneficial because a system may select those mechanisms that perform best under varying environmental conditions. We consider transitions on the overlay (by switching between different stream delivery schemes on the application layer) as well as on the underlay (by switching between different wireless topologies).**

At the beginning of our demonstration, some few devices receive the video stream from a central server. Then, additional devices start receiving the video stream. Under these circumstances, a transition from the client/server delivery scheme to a decentralized peer-to-peer based video streaming improves scalability. On the underlay, video stream delivery benefits from topology control mechanisms, which select specific wireless neighbors in order to restrict communication to energy-efficient communication links. However, topology control also reduces the robustness of the underlay topology. Thus, when devices that are critical nodes in the wireless network are on the verge of running out of energy, we conduct a transition to a more robust underlay topology. In summary, by performing transitions jointly on multiple layers, we demonstrate resulting improvements of energy efficiency, scalability and robustness.

***Index Terms*—topology control, video streaming, overlay, underlay, transition**

I. Introduction

More than ever before, networks suffer from rapidly changing environmental conditions resulting in varying performance characteristics. To cope with these network dynamics, the Collaborative Research Center on 'Multi Mechanism Adaptation for the Future Internet' (MAKI) investigates the idea of switching between different network mechanisms at runtime. This concept and a methodology to describe and execute transitions has been given by Frömmgen et al. [1]. Two existing demonstrations [2], [3] showcase the advantages of transitions in a video streaming application overlay. Richerzhagen et al. [2] support transitions between a client/server and a peer-to-peer (P2P) overlay to address scalability of the streaming system. Wilk et al. [3] adapt between unicast and broadcast delivery schemes for an increased efficiency in video streaming. Therefore, the geographic closeness of video streaming clients is monitored and exploited to trigger transitions.

This work extends the existing work in [2], [3] by introducing transitions on the underlay. Especially in large video streaming networks, the selection of an ideal underlying delivery topology has a significant effect on both the energy efficiency and the robustness of the application. We consider two types of topologies for our transitions on the underlay: a *maxpower* topology and a *sparse* topology. In a maxpower topology, two nodes are neighbored if they are contained in the maximum transmission range of each other. Such a topology is on one hand very robust against churn of participants, but is on the other hand suboptimal in terms of energy efficiency. In contrast, a sparse topology is constructed by a topology control mechanism. The basic idea of topology control is that a subset of the communication links available in the maxpower topology is selected for each network device [4], [5]. While topology control leads to energy-efficient communication topologies, these topologies tend to be less robust due to the removal of redundancy from the network.

This demonstration illustrates how performing transitions between maxpower and sparse underlay topologies in conjunction with transitions on the video streaming overlay improves energy efficiency, scalability, and robustness of the application.

Our demonstration scenario is as follows: Initially, some few battery-powered video streaming devices receive a live stream based on a client/server delivery scheme. Topology control is enabled in order to address the energy efficiency of the network. After some time, additional devices join the wireless network in order to stream the video. As soon as the server gets overloaded, we switch to the self-adaptive P2P streaming overlay Transit [6] on basis of the Simonstrator simulation and prototyping platform [7] to be able to reliably distribute the stream to all participants. Some devices, in particular the ones located close to the server, have been carrying an increased load so far and are thus likely to run out of energy earlier than other devices. As the underlay topology is sparse due to the execution of topology control, alternative routes are missing for the moment when such nodes become unable to forward the video stream. For this reason, we disable topology control, i.e., we conduct a transition to the maxpower underlay topology when application-critical nodes are on the verge of running out of energy.

II. Considered Transitions

As outlined in Section I, we consider two types of transitions in our demonstration: transitions on the overlay and transitions on the underlay.

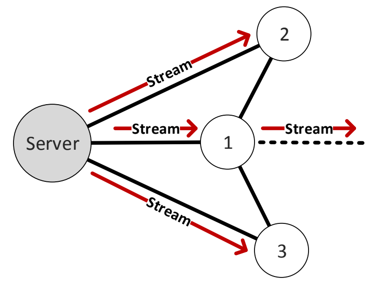
A. Overlay Transitions

On the overlay, we switch between different video streaming delivery schemes, as proposed in the Transit P2P video streaming system [2], [8]. In the case of only few streaming devices, a client/server delivery scheme is well-suited because of its low overhead for the battery-powered devices. A client/server delivery scheme essentially reflects a star topology where each device receives the video stream via unicast directly from the server. However, servers are inherently restricted with respect to their maximum bandwidth; for this reason, the client/server delivery scheme does not scale well with the number of streaming devices. Therefore, we conduct a transition from the client/server delivery scheme to a P2P-based delivery scheme based on Transit by Wichtlhuber et al. [6], which allows to conduct topology optimizations as proposed by Rückert et al. [8]. The P2P delivery scheme is more scalable because every participant of such a network contributes to the delivery of the stream. However, due to the inherent maintenance overhead of P2P overlays, it is beneficial to switch back to the client/server delivery scheme when the number of participants drops again.

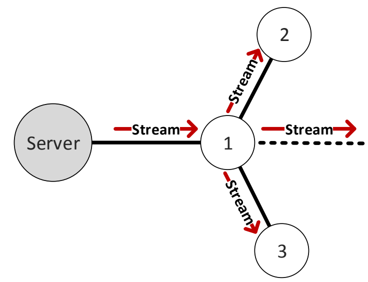
B. Underlay Transitions

In addition, our demonstration allows for the execution of transitions between different wireless underlay topologies. The properties of the underlay are essential for the robustness and energy efficiency of video streaming because the underlay specifies which routes may be used for delivering the stream.

Typically, all devices in a wireless ad-hoc network send with maximum transmission power to be able to reach as many other devices as possible. Such a topology, which we call maxpower topology, is shown in Fig. 1a. While being very robust due to its high density—leading to multiple alternative routes between nodes—the maxpower topology is typically suboptimal in terms of energy efficiency for two main reasons: (1) The maxpower topology contains long-distance communication links. As the power required for sending a packet over a link increases at least quadratically with the distance [9], using multiple short-distance links is often cheaper regarding the energy consumption than using one long-distance link. As the routing in overlay mechanisms like Transit is typically not optimized for the specific characteristics of the underlying communication medium, these energy-inefficient links may be



(a) Maxpower topology



(b) Sparse topology

Fig. 1: Two underlay topologies with overlay streaming routes

used for communication. (2) Routing mechanisms often rely on flooding of messages through the network, i.e., a device receiving a corresponding packet re-broadcasts this packet to its neighbors. Dense topologies such as the maxpower topology cause, among others, the increased occurrence of redundant re-broadcasts, high interference and frequent collisions.

The basic idea of topology control is to increase the energy-efficiency of the network by removing communication links from the topology [4]. Having determined a set of logical neighbors, each device may then shrink its transmission range such that the device is still able to reach its farthest logical neighbor [10]. For our demonstration, we use the topology control mechanism kTC [11]. Executing kTC, each device removes the longest link from triangles found in the local topology. Based on this simple rule, kTC maintains a sparse topology as shown in Fig. 1b. Recently, it has been shown that the kTC topology may lead to energy savings in a hardware testbed [12].

Nevertheless, the sparse topology constructed by topology control is not always the first choice. Compared to the maxpower topology, the robustness of the sparse topology is lower. For this reason, a failing node may have a crucial negative impact on the application performance. For example, removing device 1 from the sparse topology shown in Fig. 1b would partition the network. As a result, other devices in the topology would not be able to stream the video anymore until topology control would update the underlay topology.

To avoid this problem, we conduct a transition from the sparse topology to the maxpower topology when application-critical devices are about to run out of energy. As alternative routes will then be available again, the overlay (e.g., Transit) may use these routes as soon as a device vanishes from the

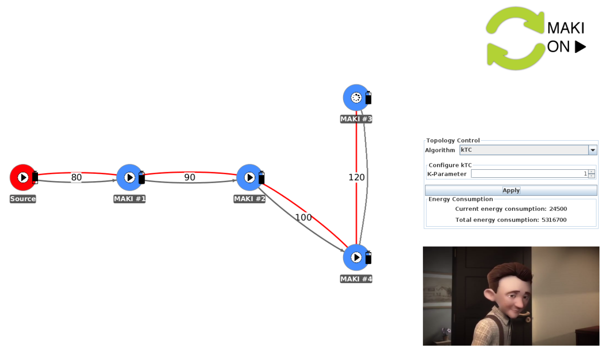


Fig. 2: Screenshot of the view of the laptop

network. In the best case, the streaming overlay will immediately switch to new communication routes, thus, decreasing the load of the low-power device.

III. Demonstration Setup

Our demonstration illustrates insights in developing efficient, adaptive approaches for wireless video streaming that jointly optimize the application-specific overlay and the wireless underlay. The demonstration setup consists of a laptop, which hosts the resource-constrained video streaming server, and four Nexus 7 tablets, which play the video stream. Laptop and tablets may communicate via a WiFi access point.

The course of the demonstration may be observed and controlled on the user interface being executed on the laptop. Fig. 2 shows a screenshot of this user interface. The panel on the right-hand side contains controls to trigger transitions in the network and a view of the current position in the video stream (on the server). The left-hand side shows the current state of the system: The laptop and the tablet devices are depicted as red and blue circles with a state and a battery indicator. The routes used by the overlay are shown as red lines, and the underlay communication links are shown as gray lines labeled with a weight that signifies their relative distance.

The video streaming client on the mobile devices includes the played back video stream as well as an illustration of the playback buffer and network statistics of the device.

For the sake of a practical demonstration, all devices are placed on a single table. To demonstrate the benefits of topology control, the system allows for configuring virtual locations of the devices. The virtual distance between devices then serves for topology control as an indicator of the energy efficiency of the corresponding underlay link. We estimate the communication cost based on the virtual distance between devices (assuming that topology control adjusts the transmission power based on distance). Furthermore, we integrate a virtual battery meter on the mobile devices; i.e., the battery level of devices can be modified arbitrarily for demonstration purposes.

In the following, we delineate the course of our demonstration: In the beginning, two tablets join the highly resource-constrained video streaming server, which cannot serve more than three clients directly. Topology control is enabled right from the beginning to ensure that only energy-efficient underlay links may be selected for video stream forwarding. After establishing the video stream on the two tablets, two more devices join, driving the server to its bandwidth capacity, which may be observed by the stalling video on some of the devices. At this point, we conduct a transition to a P2P distribution scheme, which leads to a reliable delivery of the video stream to all tablets. The arrangement of the tablet devices in our demonstration setup resembles Fig. 1b, which leads to a rapid depletion of the battery of one tablet, finally causing it to leave the topology earlier than the other tablet devices. At this point, the other tablet devices no longer receive the video stream until the disabled underlay links would be re-activated again (e.g., by a periodic re-execution of topology control). This situation shows that disabling topology control in a *proactive* way could have prevented the stalling video *and* the early leaving of the overloaded node: If we conduct an underlay transition to the maxpower topology prior to the failure of the overloaded tablet device, alternative routes for redirecting the video stream are immediately available. Additionally, the alternative routes may even extend the lifetime of the overloaded node.

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