Software-Defined Networking in an Industrial Multi-Radio Access Technology Environment

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1 INTRODUCTION

The trend towards Industry 4.0 considers a wide range of new use cases in the context of the factory of the future. These new industrial applications range from augmented workspace applications which require high bandwidth wireless links to deliver information in nearly real-time to others which require seamless mobility and continuous connectivity for wirelessly connected automated guided vehicles (AGVs) to permanently communicate with a back end system. Several scenarios in the context of the factory of the future require ultra-fast and reliable wireless transmission together with real-time processing, e.g., analysis of video data in an Edge Cloud to minimize the delay. Accordingly, wireless connectivity is paving its way into the factories of the future to enable these new applications. Moreover, the concept of Software-Defined Networking (SDN), with the split of the control and data plane, seems a natural fit to programmatically orchestrate networks and slices in the factories of the future, with its vast range of requirements set by the aforementioned use cases.

The wireless connectivity can be realized in the licensed bands (e.g., LTE or 5G) and/or unlicensed ISM bands (e.g., 2.4 and 5 GHz). The former, comes with the burden to acquire the right for communication in a specific frequency band. The latter, however, comes with the burden to acquire the right for communication in a specific frequency band. The latter, however, comes with less guarantees with regards to the communication channel. In particular, communication in the ISM bands usually relies on random medium access schemes, and thus can hardly support any real-time applications. Moreover, it may heavily suffer from packet loss, e.g., caused by link impairments such as collisions and hidden terminals.

Indeed, millimeter wave (mmWave) connectivity (e.g., 28 and 60 GHz), can provide much higher throughput and low latency links [3] due to the increased channel bandwidth compared to the lower ISM bands. Furthermore, the challenging properties of strong directivity and high attenuation increase the spatial reuse on the same channels while increasing the robustness against jamming. These specific transmission characteristics on the physical layer render mmWave well for the factory of the future [1]. However, mmWave comes with the challenge to provide seamless mobility. In particular, the very narrow directed wireless links, attenuation, and small cell coverage require a permanent adjustment of the physical transmission settings in case of client mobility.

One way to overcome the challenges of mmWave technology in the context of mobility is to leverage multiple end-points simultaneously, either of the same technology, i.e., multi-connectivity networks, or of different technologies, i.e., multi-radio access technology (multi-RAT) networks. These setups gain from antenna/spatial diversity within the challenging radio environment, e.g., as present in factories.

In this demo, we combine mmWave technology with the concept of SDN to bring the high bandwidth and low latency wireless connectivity together with seamless mobility into the factories of the future. Accordingly, the SDN control plane needs to provide the means to measure the link quality to perform link selection in an industrial multi-RAT environment. This requires measurements of the wireless data path to properly adjust the transmission settings in a timely manner. While previous work [2] solely focused on video streaming via a multi-RAT setup (WiFi and WiMAX) in the sub 6 GHz band, in our demo, we consider near real-time applications in an industrial environment using promising mmWave approaches.
Control Plane
Data Plane

Application Manager

Video Encoder

Video Decoder

Remote monitoring
Switch (OpenFlow)

Wired connection
Mobile Unit / AGV

Wireless data plane
Control plane

Segment #1
Segment #3
Segment # 2
Rate #3Rate #2Rate #1

Figure 1: The Demo - implemented demonstrator for mobility with high-rate stream transmission

2 DEMONSTRATOR

2.1 Concept

Figure 1(a) depicts a conceptual visualization of this demo. Here, a moving vehicle with multiple wireless interfaces is transmitting a live video stream over one or more high-bandwidth wireless links to a control center. We rely on mmWave links to deliver the video stream over the low latency and high throughput links to the application manager. The control channel is realized via a wireless link which provides sufficient throughput, i.e., LTE, WiFi or 5G in the near future.

The video stream is sent via multiple high throughput links and processed within an Edge Cloud close to the wireless access to analyze the data in a timely manner. Furthermore, the stream is duplicated and forwarded to the control center to interrupt the robot’s action if necessary.

2.2 Prototype Implementation

Our AGV (mobile robot) is based on the commercial Festo Robotino platform. The AGV is equipped with a video camera, multiple wireless interfaces, and an OpenFlow (OF) Switch. The AGV continuously provides an HD-SDI (720p and 60 fps) video stream. We use a low-latency video codec implementation on a dedicated FPGA-based hardware decoder board to encode the HD-SDI signal into a H.264 baseline profile bitstream which is then sent via multi-cast. Finally, the video is decoded by the same hardware platform and also in software using ffmpeg. The video encoding and decoding process by the dedicated hardware platform together with the wireless transmission latency adds up to 20 ms delay, this enables the visual inspection use case.

In our setup, we leverage WiFi for the control channel and two 60 GHz mmWave links for the data plane. Here, we rely on (i) a proprietary platform and (ii) an experimental IEEE 802.11ad-based platform as wireless links. While the former does not expose any link quality information or access to physical layer parameters, the latter provides access to both, i.e., the latter allows to gain information such as the received signal strength. However, it does not provide access to channel state information for fine-grained channel statistics.

We collect packet-based statistics at the OF switch nearest to the wireless access points (APs), i.e., the stationary OF switch (see Figure 1(a)). This also keeps the system independent of the used wireless technologies. Furthermore, we rely on a dedicated wired or wireless out-of-band control channel between the control plane (CP), the OF switches and APs. Our CP leverages the packet delivery ratio (PDR) information and wireless statistics if available. Our CP uses link statistics to identify additional potential links to increase the transmission robustness. An additional link is added when a new link becomes available and the current link quality decreases.

At the core, the system also takes the PDR for each flow into account to realize fast switching on a per flow basis, i.e., the flow with the highest PDR is rated best.

Here, we have realized mechanisms to prevent oscillation. In particular, a relative threshold \( T_{PDR} \) prevents unnecessary switching. The best flow’s PDR needs to exceed \((1+T_{PDR}) \cdot P_c\), where \( P_c \) is the current flow’s PDR. This works well, when the statistics are gathered on a common switch. When the statistics are gathered on different switches the PDRs are hardly comparable, i.e., an additional offset in time between the PDRs may occur due to transmission delay.

In our demo, we showcase a system where a wireless connected AGV offloads the visual inspection of live HD video data to an Edge Cloud in an industrial setting using multi-RAT as depicted in Figure 1(b). Here, we utilize several different wireless access technologies, which come with different challenges. However, in our SDN control- and data-plane, we have realized mechanisms, which allow us to deploy this scenario even today with off-the-shelf wireless technology.

Demo video: https://tinyurl.com/ycas9up5

REFERENCES