ERCIM fellowship Programme

Final scientific report

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Host Organisation	RISE Research Institutes of Sweden AB, Stockholm, Sweden
Scientific coordinator	Prof. Thiemo Voigt

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

The scientific activity during the fellowship was focussed on the following research application areas:

1. Aerial drone network
2. Human-machine interaction
3. AI for next generation wireless networks
4. End-to-end quality assurance

A part of the research programme was focused on developing a novel aerial drone framework specifically conceived for application-level functionality rather than low-level control mechanisms. It includes efficient video surveillance of inaccessible regions. This was done as a part of a project from SSF (Stiftelsen för Strategisk Forskning) and Digital Futures, a cross-disciplinary research centre established in 2020 by KTH, Stockholm University and RISE.

Another part of the research programme was focused to developing a novel remote-control moving platform testbed using toy truck. It included investigating video-based remote-control based semi-autonomous control of heavy industrial machinery. We conducted user experience assessment experiments for this study using the lab-based testbed and dedicated wireless network. Furthermore, we developed next-generation network solutions for end-to-end quality assurance and video services. The use cases like immersive video transmission, vehicular networks, video surveillance, extended (augmented) reality, and in-flight entertainment have also been studied and closed loop network solutions have been developed based on AI and QoE assurance. This research was supported by internal funds and CELTICNEXT.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

The following research papers were published during the fellowship duration:

1. C. Singhal and S. Barick, "ECMS: Energy-Efficient Collaborative Multi-UAV Surveillance System for Inaccessible Regions," in *IEEE Access*, vol. 10, pp. 95876-95891, Sep. 2022, doi: 10.1109/ACCESS.2022.3206375.

- Abstract: The evolution and popular adaptation of drone technology in diverse applications has necessitated advancement of UAV communication framework. UAVs inherently support features like mobility, flexibility, adaptive altitude, which

make them a preferable option for dynamic surveillance of remote locations. Multiple UAVs can cooperatively work to accomplish surveillance missions more efficiently. However, the intermittent network connectivity and the limited onboard energy storage impose a great challenge on UAV-assisted remote surveillance. This paper presents an Energy-efficient Collaborative MultiUAV Surveillance (ECMS) system for surveillance of inaccessible regions. The system employs an optimal Multi-UAV Collaborative Monocular Vision (MCMV) topology to facilitate the surveillance with zero blind spot using minimum number of drones. We also propose an application-aware Multi-Path Weighted Load-balancing (MWL) routing protocol for handling congestion by distributing traffic among all available resources in UAV network and adaptively selecting the of source datarate (i.e. switching video resolution). The simulation results demonstrate that the proposed surveillance system achieves coverage with lesser number of UAVs compared to the existing systems. It also achieves higher throughput, higher packet-delivery ratio, higher residual energy of UAVs, and lower end-to-end delay.

2. C. Singhal, "I2MB: Intelligent Immersive Multimedia Broadcast in Next-Generation Cellular Networks," in *IEEE Access*, vol. 10, pp. 98882-98895, Sep. 2022, doi: 10.1109/ACCESS.2022.3207180.

- Abstract: The popularity of immersive multimedia content is prevalent and the consumption of 360-degree videos is increasing rapidly in varied domains. The broadcast of such content in cellular networks will be challenging in terms of dynamic content adaptation and efficient resource allocation to serve heterogeneous consumers. In this work, we propose an intelligent immersive new radio multimedia broadcast multicast system (NR-MBMS), I2MB, for next-generation cellular networks. I2MB intelligently forecasts the users' viewing angle and the 360-degree video tiles to be broadcast beforehand using long short-term memory network. We define broadcast areas by using modified K-means clustering. The complex multivariable optimization problem that integrates efficient adaptive 360-degree video encoding and tiled broadcast using optimized transmission parameters is defined as as a Markov decision process (MDP). In a dense urban scenario with a large MBSFN (multimedia broadcast multicast service single frequency network) synchronization area, the state and action space dimensionality is very high, in which the solution is obtained by using deep deterministic policy gradient (DDPG) algorithm. I2MB incorporates deep reinforcement learning based radio resource allocation (modulation-coding scheme and frequency-time resource blocks) and tiled video encoding to maximize the viewport video quality experienced by the broadcast mobile users. I2MB provides improved immersive video broadcast streaming quality while serving a higher number of mobile users. Adaptive encoding of 360-degree video tiles and radio resource allocation are performed based on users' forecasted viewing angle, spatial distribution, channel conditions, and service request. The performance evaluation of our proposed scheme, I2MB, shows considerable gains in viewport quality (46.83%) and number of users served (30.52%), over a recent state-of-the-art method VRCAST.

3. C. Singhal, M. Ghosh, Himanshu Mittal, and Pravartya Dewangan, "MAIVS: Machine Learning Based Adaptive UHD 360-degree Immersive Video Streaming," *IEEE International Conference on Communications Workshop (ICC-W) MetaNC*, Rome, Italy, May 2023, pp. 1-6.

- Abstract: The 360-degree video transmission offers an immersive experience to

viewers and is an integral part of several applications such as Metaverse. Ultra-High Definition (UHD) or greater resolutions for such content requires a substantially higher bitrate for transmission even when encoded using the latest codecs. In this work, we propose a machine learning based adaptive UHD 360-degree immersive video streaming solution, MAIVS, that reduces the data rate requirement to stream the high resolution 360-degree immersive videos. We divide the videos spatially into motion constrained tiles (MCTS), encode (using HEVC), and package them into mp4 containers at different quality levels. We train a Deep Neural Network (DNN) model for each segment of the video to upscale (at client) it to a higher resolution. We use the DASH (dynamic adaptive streaming over HTTP) framework for streaming the video tiles and the model parameters in a progressive manner. The tiles directly in the viewers Field of View (FoV) are streamed at the highest possible quality while a lower resolution is used for the other tiles. We use video quality parameter (PSNR), buffer conditions, and available network bandwidth, as feedback to train the Deep Q-network (DQN) and selectively pack the bitrate quality segments accordingly. Overall, by using reinforcement learning in our proposed MAIVS framework, we improve the client-side PSNR while reducing the bitrate requirement for streaming high resolution (UHD and higher) 360-degree videos over the internet.

4. C. Singhal, "Sustainable Application Support in Battery-less IoT Sensing Network System," *IEEE International Conference on Communications Workshop (ICC-W) SIGNIS*, Rome, Italy, May 2023, pp. 1-6.

- Abstract: The future Internet-of-Everything (IoE), supported by the 6G and beyond wireless networks, will include batteryless intermittent computing (internet-of-things) IoT devices that use energy-harvesting power to support heterogeneous applications in diverse domains like smart-city, smart-infrastructure, environment-monitoring, and disaster scenarios. These devices need to operate sustainably in scarce-intermittent energy conditions and challenging environments. Energy buffers, implemented using small capacitors, support the execution of tasks like sense, send, receive, and control, that are associated with the concerned user-applications. In this article, we identify the enduser application support requirements and associated elements in intermittent computing IoT device network systems.

5. S. Rafiei, C. Singhal, K. Brunnstrom, and M. Sjostrom, "Human Interaction in Industrial Tele-Operated Driving: Laboratory Investigation," *IEEE International Conference on Quality of Multimedia Experience (QoMEX)*, Ghent Belgium, June 2023, pp. 1-4.

- Abstract: Tele-operated driving enables industrial operators to control heavy machinery remotely. By doing so, they could work in improved and safe workplaces. However, some challenges need to be investigated while presenting visual information from onsite scenes for operators sitting at a distance in a remote site. This paper discusses the impact of video quality (spatial resolution), field of view, and latency on users' depth perception, experience, and performance in a lab-based tele-operated application. We performed user experience evaluation experiments to study these impacts. Overall, the user experience and comfort decrease while the users' performance error increases with an increase in the glass-to-glass latency. The user comfort reduces, and the user performance error increases with reduced video quality (spatial resolution).

The following research papers were prepared during your fellowship period and are still

pending:

1. C. Singhal, S. Rafiei, and K. Brunnstrom, “Real-time Live-Video Streaming in Delay-Critical Application: Remote-Controlled Moving Platform,” *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Toronto, Canada, Sep. 2023, pp. 1-7 (submitted).
2. C. Singhal, T. Voigt, and L. Mottola, “ Application Aware Energy Attack Mitigation in Intermittent Computing System”. (to be submitted).

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

I participated in the following events during the fellowship period:

1. IEEE International Conference on Communications (ICC), 29 May-01 June, 2023, Rome, Italy.
    - Presentation in MetaNC and SIGNIS workshops. Session chair for MWN-4 and MWN-7 sessions
2. Assist Project Workshop, 02 May-03 May, 2023, Knivsta, Sweden.
3. International workshop on Advances in Planar Antennas and Communication Technology, 14 March 2023, online
    - Delivered an invited talk on “Hybrid cognitive radio system for 5G/6G networks”..
4. International Conference on Electronic and Photonic Integrated Circuits (EPIC) for Applications to: AI & ML, Quantum Communication, Healthcare, MOEMS, RF & THz, Dec. 16, 2023, online.
    - Delivered an invited talk on “Machine learning based user-centric efficient immersive media transmission ”
5. Assist project meeting, 16 Nov., 2022, Uppsala, Sweden.
    - Presented work on “Application-aware energy-attack mitigation for intermittent computing systems ”
6. DRDO sponsored workshop on Machine Learning Algorithms for Wireless Communication Networks, 05 Nov, 2022, online
    - Delivered a keynote presentation on “Machine learning based efficient multimedia transmission over wireless networks”.
7. RISE Computer Science department conference, 09 July, 2022, Upplands Vasby, Sweden.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

The research Exchange Programme (REP) visit details are as follows,
name of the REP Organisation: CNR-IEIIT, Turin
country: Italy
local scientific coordinator: Dr. Francesco Malandrino
dates: 12 Dec to 16 Dec 2022.
The REP helped me to start a joint research work on dynamic DNN training orchestration in Internet-of-everything networks.