

Computer Communications Laboratory



Anh T. Pham
Professor



Cong-Thang Truong
Senior Associate Pro-
fessor



Tongiun Huang
Assistant Professor

In the AY2016, the Computer Communications Laboratory (CCL) has three faculty members, one visiting scholar, Dr. Chuyen T. Nguyen (Hitachi Fellow) from Hanoi University of Science and Technology, and 9 graduate students (MS/PhD) working as research assistants. We have extensive collaborations with different research groups in Vietnam, Korea, UK and France. Our research sponsors include both Japanese agencies, including Japan Society for Promotion of Science (JSPS), the Japan Science Society (JSS), Telecommunication Advancement Foundation (TAF) etc., and international ones, such as Electronics and Telecommunications Research Institute (ETRI, Korea) and National Foundation for Science and Technology Development (NAFOSTED, Vietnam).

Our research and education focus on the areas of computer networks, multimedia communications and networks, optical/wireless communications and networking technologies, communication engineering, and ubiquitous computing & its applications. Especially, we recently encompass following topics:

1. Visible light communications (VLC) and its Applications in Indoor Positioning. The future of lighting is currently moving in the direction of being multifunctional; modern light sources have the capacity for illumination and concurrent wireless data transmission. The merger of these two applications has been made possible through solid-state high brightness light emitting diode (LED) technology. Short-range optical wireless communication utilizing the visible spectrum emitted from the LEDs, referred to as visible light communication (VLC) transmits data via modulation of the light intensity. So far the VLC capability is above 1 Gbps with a reasonable coverage range that is applicable for home/office environment. The dual functionality required from the LED creates the unique opportunity for indoor localization which is much more precise than RF counter-

part. Our research focuses on development of smart lighting systems that support high-speed, multiuser data transmission and VLC-based indoor localization, which will play a crucial part in the paradigm of the Internet of Things.

2. Quality of Experience (QoE) Modelling. Multimedia contents are increasingly being created in different formats, standards, modalities, and complexities. Meanwhile, the users are consuming the contents through a variety of terminals and network connections. Different users may use a wide variety of terminals with very different capabilities (in terms of screen sizes, processors, etc.) to consume multimedia contents from different sources. This fact results in big challenges for providers to provide good Quality of Experience (QoE) for users today. In this research, we investigate the influence factors and models for the overall QoE perceived by users at their devices. Especially, through the models, we try to reveal the insights into the influence factors of the overall quality, thus leading to suggestions to improve the quality of multimedia contents.

3. Internet Video Streaming. In a recent study, Cisco predicts that 90 percent of the bits carried on the Internet will be video traffic in the near future. Video streaming over IP networks has been conventionally based on the Real-time Transport Protocol (RTP) or some variations of RTP. However, thanks to the abundance of Web platforms (including the Content Delivery Network - CDN) and broadband connections, HTTP (Hypertext Transfer Protocol) has become a cost effective solution for video/audio streaming nowadays. In this research, our purpose is to investigate the use of HTTP streaming for video content over the open Internet. In this context, adaptivity to network fluctuations is the most important feature. Further, we will try to support not only small resolution/bitrate video, but also large resolution (e.g. Full High-Definition) ones.

4. Free-space Optics/Millimeter-Wave Front/Backhaul of the 5G Mobile Networks. In this research, we propose hybrid architecture and enabling technologies for 5G mobile front/backhaul (F/BH) networks. We argue that a single-technology solution, either optical fiber (OF) or radio millimeter wave (mmW), is not sufficient for the 5G F/BH networks due to the requirements of enormous capacity, scalability, energy-efficiency and strict quality of service (QoS). Our contributions include fundamental studies on theoretical limits; development of analytical models and performance evaluation/optimization of novel hybrid architecture for 5G F/BH networks using three technologies of OF, mmW and free-space optics.

5. Integrated FSO/PON for Next-Generation Access Networks. Free-space optics (FSO) is a wireless line of sight technology that transmits high data rates using a narrow beam light through the air as transmission medium. The

Division of Computer Engineering

theory of the FSO transmission is basically the same as that of the fiber optics transmission. The main difference is that the air is used as transmission medium instead of fiber. The transmission rate may reach gigabit-per-second rates over few kilometers. FSO communication has the advantage of ease of setup and tear down, provision of access in difficult locations, and lower cost. Our research exploits the possibility of employing FSO in a part of practical optical access networks. In particular, we consider the integration of FSO and passive optical networks (PONs). Being more flexible, cheaper, easier and faster to install than the conventional PONs, FSO/PON has been viewed as a potential candidate technology for future optical access networks.

We always welcome undergraduate and graduate students who are interested in the above mentioned research. For further information, visit our website at <http://www.u-aizu.ac.jp/labs/ce-cc/>.

Refereed academic journal

- [pham-207-035-01:2016] Phuc V. Trinh, Ngoc T. Dang, Truong C. Thang, and Anh T. Pham. Performance of All-optical Amplify-and-Forward WDM/FSO Relaying Systems over Atmospheric Dispersive Turbulence Channels. *IEICE Transaction on Communications*, E99-B(6):1255–1264, June 2016.

This paper newly proposes and theoretically analyzes the performance of multi-hop free-space optical (FSO) systems employing optical amplify-and-forward (OAF) relaying technique and wavelength division multiplexing (WDM). The proposed system can provide a low cost, low latency, high flexibility, and large bandwidth access network for multiple users in areas where installation of optical fiber is unfavorable. In WDM/FSO systems, WDM channels suffer from the interchannel crosstalk while FSO channels can be severely affected by the atmospheric turbulence. These impairments together with the accumulation of background and amplifying noises over multiple relays significantly degrade the overall system performance. To deal with this problem, the use of the M-ary pulse position modulation (M-PPM) together with the OAF relaying technique is advocated as a powerful remedy to mitigate the effects of atmospheric turbulence. For the performance analysis, we use a realistic model of Gaussian pulse propagation to investigate major atmospheric effects, including signal turbulence and pulse broadening. We qualitatively discuss the impact of various system parameters, including the required average transmitted powers per information bit corresponding to specific values of bit error rate (BER), transmission distance, number of relays, and turbulence strength. Our numerical results are also thoroughly validated by Monte-Carlo (M-C) simulations.

- [pham-207-035-02:2016] Thanh V. Pham and Anh T. Pham. Performance of APD-based Amplify-and-Forward Relaying FSO Systems over Atmospheric Turbulence Channels. *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, E99-A(7):1455–1464, July 2016.

This paper proposes and theoretically analyzes the performance of amplify-and-forward (AF) relaying free-space optical (FSO) systems using avalanche photodiode (APD) over atmospheric turbulence channels. APD is used at each relay node and at the destination for optical signal conversion and amplification. Both serial and parallel relaying configurations are considered and

Summary of Achievement

the subcarrier binary phase-shift keying (SC-BPSK) signaling is employed. Closed-form expressions for the outage probability and the bit-error rate (BER) of the proposed system are analytically derived, taking into account the accumulating amplification noise as well as the receiver noise at the relay nodes and at the destination. Monte-Carlo simulations are used to validate the theoretical analysis, and an excellent agreement between the analytical and simulation results is confirmed.

[pham-207-035-03:2016] Phuc V. Trinh, Truong C. Thang, and Anh T. Pham. Mixed mmWave RF/FSO Relaying Systems over Generalized Fading Channels with Pointing Errors. *IEEE Photonics Journal*, 9(1-14):1–14, Feb 2017.

This paper studies the performance of mixed millimeter-wave radio-frequency (mmWave RF), free-space optics (FSO) systems in a highly scalable and cost-effective solution for fifth-generation (5G) mobile backhaul networks. The mmWave RF and FSO fading channels are, respectively, modeled by the Rician and the generalized Malaga (M) distributions. The effect of pointing errors due to the misalignment between the transmitter and the receiver in the FSO link is also included. Novel accurate closed-form expressions for the cumulative distribution function, the probability density function, and the moment generating function (MGF) in terms of Meijer's G functions are derived. Capitalizing on these new results, we analytically derive precise closed-form expressions for various performance metrics of the proposed system, including the outage probability, the average bit error rate (ABER), and the average capacity. Additionally, new asymptotic results are provided for the outage probability, the MGF, and the ABER in terms of simple elementary functions by applying the asymptotic expansion of the Meijer's G function at high signal-to-noise ratios (SNRs). Numerical results further validate the mathematical analysis by Monte-Carlo simulations.

[thang-207-035-01:2016] H. T. T. Tran, H. T. Le, N. N. Pham, A. T. Pham, and T. C. Thang. Quality improvement for video on-demand streaming over HTTP. *IEICE Trans. Information & Systems*, E100.D(1):61–64, Jan. 2017.

It is crucial to provide Internet videos with the best possible content value (or quality) to users. To adapt to network fluctuations, existing solutions provide various client-based heuristics to change the bitrate without considering the actual quality. In this work, we propose for the first time an adaptation method, which employs a quality model in making decisions. The proposed

method also estimates the buffer level in the near future to prevent the client from buffer underflows. Experimental results show that the proposed method can consistently achieve high video quality while still providing buffer stability.

- [thang-207-035-02:2016] H. T. T. Tran, N. N. Pham, A. T. Pham, and T. C. Thang. A Histogram-based Quality Model for HTTP Adaptive Streaming. *IEICE Trans. Fundamentals*, E100-A(2):555–564, Feb. 2017.

HTTP Adaptive Streaming (HAS) has become a popular solution for multimedia delivery nowadays. Because of throughput variations, video quality fluctuates during a streaming session. Therefore, a main challenge in HAS is how to evaluate the overall video quality of a session. In this paper, we explore the impacts of quality values and quality variations in HAS. We propose to use the histogram of segment quality values and the histogram of quality gradients in a session to model the overall video quality. Subjective test results show that the proposed model has very high prediction performance for different videos. Especially, the proposed model provides insights into the influence factors of the overall quality, thus leading to suggestions to improve the quality of streaming video.

- [thang-207-035-03:2016] H. T. Le, N. N. Pham, A. T. Pham, and T. C. Thang. A probabilistic adaptation method for HTTP low-delay live streaming over mobile networks. *IEICE Trans. Information & Systems*, E100.D(2):379–383, Feb. 2017.

The study focuses on the adaptation problem for HTTP low-delay live streaming over mobile networks. In this context, the client’s small buffer could be easily underflowed due to throughput variations. To maintain seamless streaming, we present a probabilistic approach to adaptively decide the bitrate for each video segment by taking into account the instant buffer level. The experimental results show that the proposed method can significantly reduce buffer underflows while providing high video bitrates.

Refereed proceedings of an academic conference

- [pham-207-035-04:2016] Phuc V. Trinh, Truong C. Thang, and Anh T. Pham. Two-Way All-Optical AF Relaying FSO Systems over Malaga (M) Channels with Pointing Errors. In *Proc. of the 2016 IEEE International Conference on Communications (ICC’16)*, pages 1–7, Kuala Lumpur, May 2016. IEEE.

Summary of Achievement

Two-way transmission protocol is an efficient method to overcome the spectral loss incurred due to half-duplex communication. In this paper, we propose to implement two-way transmission in an amplify-and-forward (AF) relaying free-space optical (FSO) system utilizing an AF relay with optical amplifier. The performance of the proposed FSO system using subcarrier intensity modulation (SIM) with intensity modulation/direct detection (IM/DD) over independent but not necessarily identically distributed (i.n.i.d) Malaga (M) atmospheric turbulence channels in presence of pointing errors is studied. Exact closed-form expressions for the moment generating function (MGF) and cumulative distribution function (CDF) of the end-to-end signal-to-noise ratio (SNR) are obtained in terms of extended generalized bivariate Meijer's G-functions (EGBMGF). Capitalizing on these new results, we derive exact closed-form expressions for various performance metrics of the considered FSO system including the outage probability, the average bit error rate (ABER), and the ergodic achievable-rate. All analytical results are thoroughly confirmed by Monte-Carlo (M-C) simulations.

[pham-207-035-05:2016] Thanh V. Pham and Anh T. Pham. On the Secrecy Sum-Rate of MU-VLC Broadcast Systems with Confidential Messages. In *Proc. of the 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP) - 5th Colloquium on Optical Wireless Communications*, pages 1–6, Prague, Czech Republic, July 2016. IEEE.

This paper studies the secrecy sum-rate in multi-user multiple-input single-output (MU-MISO) broadcast visible light communication (VLC) systems with confidential messages. The well-known Zero-Forcing (ZF) precoding is utilized to ensure confidentiality among users. Different from radio frequency (RF) counterpart, input data signals of VLC systems are amplitude constrained. This fundamental difference makes the derivation of the secrecy capacity more complex. In this study, we investigate a lower bound on the secrecy sum-rate of all users, which is valid in high signal-to-noise ratio (SNR) regime. The secrecy sum-rate is derived for two scenarios: known and unknown eavesdropper's channel state information (CSI) at the transmitter.

[pham-207-035-06:2016] Vuong V. Mai and Anh T. Pham. Joint Queue-Aware and Channel-Aware for A Novel Operation of Hybrid FSO/RF Systems. In *2016 IEEE 84th Vehicular Technology Conference (VTC-Fall)*, pages 1–5, Montreal, Canada, Sept. 2016. IEEE.

This paper proposes a novel operation for hybrid Free Space Optics

(FSO)/Radio Frequency (RF) systems. We add a new function to current hybrid systems, which is responsible for operation mode selection (OMS). A dynamic OMS policy is proposed by taking intelligent control decisions at the transmitter taking into account states of both queue and channel (i.e. queue-aware and channel-aware). System performance metrics are analytically studied based on a combination of queuing and Markov chain theories. Numerical results quantitatively show how the proposed operation outperforms the conventional ones.

- [pham-207-035-07:2016] Truong C. Thang Thanh V. Pham and Anh T. Pham. On the Ergodic Capacity of MIMO Correlated Gamma-Gamma Fading Channels. In *2016 International Conference on Advanced Technologies for Communications (ATC)*, pages 32–37, Hanoi, Vietnam, Oct. 2016. IEEE.

This paper studies the ergodic capacity of multiple-input multiple-output (MIMO) correlated Gamma-Gamma (G-G) fading channels, particularly for free-space optical communications (FSO). Based on the atmospheric fading correlation analysis and by employing an approximation method for the sum of correlated (G-G) random variables (RVs), closed-form expressions for the capacity are derived for both equal gain combining (EGC) and maximal ratio combining (MRC) techniques. Numerical results confirm that channel correlation considerably degrades the performance of MIMO systems. Under a constraint of receiving area, we find that an optimal number of receiver aperture exists to achieve the best performance considering the negative impact of channel correlation. Monte-Carlo (M-C) simulations are also performed to validate the analytical results.

- [pham-207-035-08:2016] Thang V. Nguyen, Tu V.M. Pham, Thu A. Pham, Hien T.T. Pham, Ngoc T. Dang, and Anh T. Pham. Performance Analysis of Network-Coded Two-Way Dual-Hop Mixed FSO/RF Systems. In *2016 International Conference on Advanced Technologies for Communications (ATC)*, pages 70–75, Hanoi, Vietnam, Oct. 2016. IEEE.

In this paper, a novel two-way relaying technique based on network coding is proposed to improve the throughput of dual-hop mixed free-space optics (FSO)/radio-frequency (RF) communication systems. We investigate the performance of the proposed systems over Gamma-Gamma atmospheric turbulence and Rice/Rayleigh channels. The effect of pointing error on FSO link is also considered in our analysis. Closed-form expressions for end-to-end outage probability and bit error rate are analytically formulated, taking into account

Summary of Achievement

the physical layer impairments from both FSO and RF links as well as the receiver noise. The numerical results show the feasibility of using network-coded two-way relaying in dual-hop mixed FSO/RF systems. In addition, the comparison between the magnitudes of negative impacts caused by FSO and RF links is discussed. Based on this comparison, the recommendation for locating the relay node is given so that better performance could be obtained.

- [pham-207-035-09:2016] Chuyen T. Nguyen, Vuong V. Mai, and Anh T. Pham. TCP over Free-space Optical Links with ARQ and AMC: A Cross-layer Performance Analysis. In *2016 International Conference on Advanced Technologies for Communications (ATC)*, pages 80–84, Hanoi, Vietnam, Oct. 2016. IEEE.

This paper presents a comprehensive cross-layer analysis framework on the performance of transmission control protocol (TCP) over free-space optical (FSO) links, which employ the automatic repeat request (ARQ) and adaptive modulation and coding (AMC) schemes. From the framework, we quantify the impacts of different parameters/settings of ARQ, AMC and FSO links on TCP throughput performance. We also discuss several optimization aspects for TCP performance.

- [thang-207-035-04:2016] H. T. T. Tran, N. N. Pham, A. T. Pham, and T. C. Thang. A Multi-factor QoE Model for Adaptive Streaming over Mobile Networks. In *in Proc. IEEE GLOBECOM Workshop on Quality of Experience for Multimedia Communications (QoEMC)*, Washington D.C., U.S., Dec. 2016.

Energy saving is an important requirement for any mobile devices. Meanwhile, streaming is one of the most popular services via mobile devices now. In this paper, we study the dependence of consumed power on adapted video bitrates. A novel adaptation method is then presented to balance the requirements for high video quality and low power consumption.

- [thang-207-035-05:2016] H. T. T. Tran, T. C. Thang, and Y. M. Ro. Real-time Quality Evaluation of Adaptation Strategies in VoD Streaming. In *in Proc. IEEE DMIAF (special session on QoE in Digital Media)*, Santorini, Greece, Jul. 2016.

HTTP Adaptive Streaming (HAS) has become a popular trend for multimedia delivery nowadays. Because of throughput variations, video adaptation methods are needed to avoid buffer underflows. In this context, it is also important to evaluate the overall video quality of a session. In this paper, we investigate

a quality model that can evaluate a session quality as well as different adaptation strategies in real time. We use the histogram of segment quality values and the histogram of quality gradients in a session to model the overall video quality. Then, our quality model is employed to evaluate, for the first time, the cumulative quality of typical adaptation methods in real time. It is found that, to provide a high quality level, the client should avoid changing versions frequently and drastically.

[thang-207-035-06:2016] H. T. T. Tran, T. Vu, N. N. Pham, and T. C. Thang. A novel quality model for HTTP Adaptive Streaming. In *in Proc. IEEE Sixth International Conf. on Communications and Electronics (ICCE)*, Ha Long, Vietnam, Jul. 2016.

HTTP Adaptive Streaming (HAS) has become a popular trend for multimedia delivery nowadays. Because of throughput variations, video quality strongly fluctuates during a session. Therefore, a main challenge in HAS is how to evaluate the overall video quality of a session. In this paper, we explore the impact of quality variations on the perceptual quality of a video in HAS. We propose to use the histogram of segment quality values and the histogram of quality gradients in a session to model the overall video quality. Subjective test results show that the proposed model can capture the segment quality variations and accurately predict the overall quality of a session.

Unrefereed proceedings of an academic conference

[pham-207-035-10:2016] Thanh V. Pham and Anh T. Pham. Secrecy Sum-Rate of MU-VLC Broadcast Systems with Confidential Messages. In *2016 Tohoku-Section Joint Convention of Institutes of Electrical and Information Engineers*, August 2016.

[pham-207-035-11:2016] Vuong V. Mai Cong V. Le and Anh T. Pham. An Evaluation of TCP Performance over FSO Links using Network Simulation Ns-2. In *2016 Tohoku-Section Joint Convention of Institutes of Electrical and Information Engineers*, August 2016.

[pham-207-035-12:2016] Anh-Tuan H. Bui and Anh T. Pham. Efficient Access Protocol for Massive M2M Communications in LTE. In *IEICE General Conference 2017*. IEICE, March 2017.

Summary of Achievement

Research grants from scientific research funds and public organizations

[pham-207-035-13:2016] Anh T. Pham (PI) et al. Study and development of smart supermarket by using visible light communication (VLC) and smartphone technologies, 2015-2017.

[pham-207-035-14:2016] Anh T. Pham (Main Researcher) et al. Design and Performance Analysis of Next-Generation Cellular Backhaul/Fronthaul Networks, 2016-2018.

[pham-207-035-15:2016] Anh T. Pham (PI). Hybrid Architecture and Cross-Layer Design for Free-space Optics/ Millimeter-Wave Front/Backhaul of the Next-Generation Mobile Networks, 2016-2018.

Academic society activities

[pham-207-035-16:2016] Anh T. Pham, 2016.

Senior member

[pham-207-035-17:2016] Anh T. Pham, 2016.

Member

[pham-207-035-18:2016] Anh T. Pham, 2016.

Member

[pham-207-035-19:2016] Anh T. Pham, 2016.

Member of TPC for many other international conferences, including CSNDSP'16, NICS'16, ICCE'16, ATC'16...

[pham-207-035-20:2016] Anh T. Pham, 2016.

Peer Reviewer for many Transactions and Journals of IEEE, OSA and IEICE, including IEEE Transactions on Communications, IEEE/OSA Journal of lightwave Technology, IEEE/OSA Journal of Optical Communications and Networks, OSA Optics Express, IEEE Communications Letters etc.

Advisor for undergraduate research and graduate research

Summary of Achievement

[pham-207-035-21:2016] Pham Van Thanh. Master Thesis: On the Design of Multiuser Visible Light Communications (VLC) Networks: Performance Optimization and Security, University of Aizu, 2016.

Thesis Advisor: Anh T. Pham

[pham-207-035-22:2016] Abdoulaye Niang. Master Thesis: Performance Analysis of PPM-based FSO systems with PIN and APD Receiver over Log-normal and Negative exponential channel, University of Aizu, 2016.

Thesis Advisor: Anh T. Pham

[t-huang-207-035-01:2016] Toru Takahashi. Graduation thesis, School of Computer Science and Engineering, 2017.

Thesis Advisor: T. Huang

[t-huang-207-035-02:2016] Kento Kobayashi. Graduation thesis, School of Computer Science and Engineering, 2017.

Thesis Advisor: T. Huang

Contribution related to student management (for example, solution of a student-related problem)

[t-huang-207-035-03:2016] C6 Class Professor in Charge