

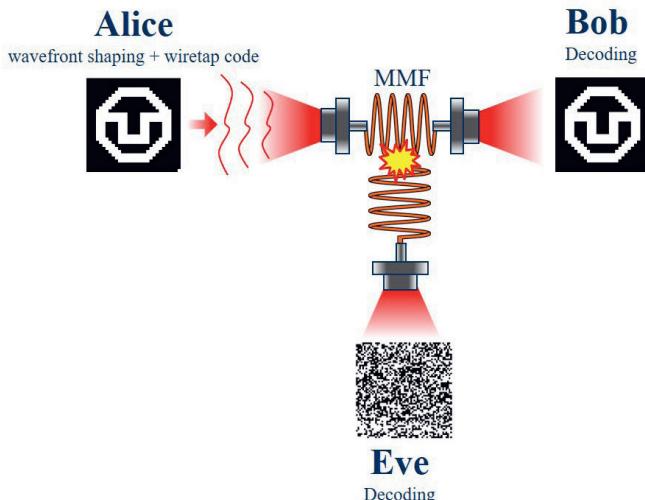
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Stefan Rothe

Harnessing Disorder of Multimode Fibres to Achieve Information Security on the Physical Layer



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Harnessing Disorder of Multimode Fibres to Achieve Information Security on the Physical Layer

Dipl.-Ing.

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*I ain't here to break it,
just see how far it will bend.*

— Joshua Homme

A great songwriter and presumably a fibre enthusiast.

Kurzfassung

Digitale Kommunikationstechniken haben das Leben innerhalb kürzester Zeit maßgeblich verändert und beeinflussen es in allen Bereichen. Dadurch steigt die Gefahr neuartiger Cyberangriffe rapide an und erfordert neue Methoden digitale Sicherheit zu gewährleisten. Als Rückgrat der globalen Digital-Infrastruktur stellen optische Kommunikationsnetze eine besonders sensible Umgebung dar. Die Multimodefaser repräsentiert hierbei einen vielversprechenden Verbindungstyp, da ihre räumlichen Pfade Netzkapazitäten signifikant anheben können. In dieser Dissertation wird ein Ansatz untersucht, mit dem ein informationstheoretisch sicherer Datenaustausch in optischen Multimodefasern erreichbar ist, indem physikalische Phänomene im Faserkanal nutzbar gemacht werden. Die Idee ist, dass die inhärente Unordnung in der Multimodefaser von einer Senderin (Alice) ausgenutzt wird, um einem legitimierten Nachrichtenempfänger (Bob) einen entscheidenden Vorteil gegenüber einer Abhörerin (Eve) zu verschaffen. Der Schlüssel sind Modenmischung, sowie modenabhängige Verluste, welche zu einem Ungleichgewicht unter verteilten Empfängern auf dem Faserkanal führen. Folglich gilt eine Entzerrung zwischen Alice und Bob zwingenderweise nicht für Eve. Diese Technik wird Sicherheit auf der Übertragungsschicht (engl.: *physical layer security*) genannt und wurde experimentell erstmalig in einer Multimodefaser umgesetzt. Durch die Messung der optischen Transmissionsmatrix können Alice und Bob einerseits ihren Kanal für eine Kalibrierung charakterisieren und andererseits geeignete räumliche Pfade identifizieren. Hierfür wurden sowohl holografische Methoden, als auch intelligente Techniken auf Basis neuronaler Netze untersucht und gegenübergestellt. Mit der TranSmissionsmatrix können Alice und Bob eine sendeseitige Vorverzerrung bestimmen, um die Lichtausbreitung durch die Faser zu kontrollieren und gezielt Informationen auszutauschen. Eve hingegen muss ihren Kanal mathematisch weiterverarbeiten. Geschickte Sendestrategien können diese Asymmetrie ausnutzen. Hierfür wurde ein Abhörexperiment durchgeführt, in dem sich Bob und Eve jeweils 50 % der übertragenen Leistung von einer 55 Moden fügenden Multimodefaser teilen. Es wird gezeigt, dass mittels spezieller Kanalkodierungen ein informationstheoretisch sicherer Datenaustausch erreicht werden kann, bei dem pro Kanalnutzung 2 Bit sicher übertragen werden können, obwohl Eve über Wissen sämtlicher Kanalzustände verfügt. Perspektivisch könnte die erreichbare Informationsicherheit weiter angehoben werden, indem Effekte zu induziertem Modenmischen oder zeitlich veränderlichen Übertragungseigenschaften im Faserkanal untersucht werden. Durch Fasern mit D-Profil oder externe mechanische Einflüsse wie Biegung oder Verdrillung können Modenmischung oder eine Zeitvarianz provoziert werden. Die Ergebnisse dieser Dissertation weisen erstmalig die experimentelle Umsetzbarkeit von *physical layer security* an einem Multimodefaserkanal nach und zeigen eine Ergänzung zur sicheren Datenübertragung in optischen Kommunikationsnetzen zukünftiger Infrastrukturen, die räumliche Informationspfade nutzen.

Abstract

Digital communication has changed life considerably in a short time and has an impact on all domains. As a result, the risk of novel cyber attacks is increasing rapidly and requires new methods to ensure information security. In particular, optical communication networks have become a crucial environment, because they represent the backbone of the global digital infrastructure. Multimode fibres are a promising link type in this context, as its spatial paths can enhance network capacities significantly. This dissertation investigates an approach to achieve information-theoretic secure data exchange in optical multimode fibres by utilising physical effects in the fibre channel. The objective is for a transmitter (Alice) to exploit inherent disorder in multimode fibre to offer a legitimate message receiver (Bob) a decisive advantage over an eavesdropper (Eve). The clue relies on both modal crosstalk as well as mode-dependent loss that lead to an imbalance among distributed receivers on the fibre channel. Consequently, equalisation between Alice and Bob necessarily does not apply to Eve. This technique is called physical layer security and is experimentally implemented on a multimode fibre for the first time. By measuring the optical transmission matrix, Alice and Bob can characterise their channel for calibration and identify suitable spatial paths. For this purpose, both holographic methods and smart techniques based on neural networks are investigated and compared. By using the transmission matrix, Alice and Bob can determine an optical pre-distortion for controlling light propagation through the fibre and exchange information. In turn, Eve must process her channel mathematically. This asymmetry can provide benefit by implementation of sophisticated transmission strategies. Therefore, an attacking experiment was carried out in which Bob and Eve share 50 % each of the transmitted power of a 55-mode fibre. It is shown that through implementation of special channel coding an information-theoretic secure data exchange can be achieved in which 2 bit can be securely transmitted per channel use, although Eve has complete channel state information. Prospectively, the achievable information security could be further enhanced by investigating effects on induced mode mixing or time-varying transmission properties in the fibre channel. D-shaped fibres or external mechanical influences such as bending or twisting can introduce mode mixing or time variance. The results obtained in this dissertation demonstrate the experimental feasibility of physical layer security on a multimode fibre channel for the first time and provide a complement for secure data transmission in optical communication networks of future infrastructures that use spatial information paths.

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