Optimizing 802.11 Wireless Communications with Machine Learning

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Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?

Thomas S. Eliot

Abstract

The high performance and low cost of 802.11 WLANs have led to the widespread adoption of this technology. However, the large set of communication features, the dynamic and unmanaged network topologies, and the unpredictable behavior of the wireless channel result in ever-increasing complex systems. These issues contribute to the creation of intractable networks that are hard to characterize by means of accurate yet scalable analytical models. Instead, sophisticated and efficient learning approaches are increasingly being considered in literature to perform this task.

In this thesis, we exploit machine learning techniques to address relevant performance issues in the context of two prominent 802.11 amendments, namely 802.11 p and 802.11 ac. The first was developed to support reliable vehicular communications, while the latter pursues the goal for high throughput in indoor environments.

To achieve high throughput, 802.11 ac defines channels of larger bandwidth than its predecessors. The resulting higher data rates come at the cost of an increased frequency variability, which is known to degrade the communication. Our first contribution is a scheme that compensates for the larger frequency variability by disabling highly attenuated OFDM subcarriers and dynamically distributing the power among the active ones. The lack of a close-form solution to the proposed throughput maximization problem increases the complexity, especially when jointly selecting the transmission rate, and limits the applicability of the method. We then present an approach that *learns* the structure of previously computed solutions and applies the gathered knowledge to provide accurate solutions at runtime.

Vehicular communications require reliable message delivery, particularly in the context of road safety applications. While the enhancements introduced in 802.11 p increase the robustness to multi-path fading, it is unclear how well vehicular communications can cope with jamming. In our second contribution, we characterize the performance of 802.11 p devices in relevant vehicular environments under the impact of jamming and identify the potential of the latter to disrupt communication over large areas thereby compromising road safety. These findings motivate our third contribution, namely a jamming detection tool based on machine learning. We capture relevant metrics from 802.11 devices and learn their behavior in different scenarios and subject to various jamming patterns, which can later be applied to accurately detect jamming attacks in indoor and vehicular environments.

In the future, users will transfer their requirements for high throughput to their vehicles. While rate adaptation provides means to achieve high throughput in vehicular environments, it is known to be a challenging task due to the fast changing channel. However, in car-to-infrastructure communications, the surroundings of an access point feature recurring characteristics that result in specific patterns of the signal strength over time. Our fourth contribution is a learning algorithm that identifies these patterns buried in empirical data and combines them with GPS information, to accurately select the rate according to the *predicted* future channel conditions.

In general, this thesis contributes various learning approaches to address relevant problems of different nature, that is, optimization, classification, and prediction, in prominent 802.11 wireless networks.

Kurzfassung

Hohe Leistungsfähigkeit und niedrige Kosten 802.11-basierter WLAN Netze haben zu der Popularität dieser Technologie beigetragen. WLAN Netze befinden sich in ständiger Entwicklung, um die Bedürfnisse der Benutzer für den stetig steigenden Durchsatz und für eine flächendeckende Verfügbarkeit zu befriedigen. Gleichzeitig steigt die Komplexität der Netze und der zugrunde liegenden Kommunikation aufgrund der zahlreichen Funktionalitäten, der wachsenden Anzahl und Mobilität der Kommunikationsgeräte und des unvorhersehbaren Verhaltens des drahtlosen Kanals. Folglich kann die Optimierung dieser Netze selten mittels akkurater und skalierbarer analytischer Modelle durchgeführt werden. Stattdessen wird der Einsatz von Machine Learning Ansätzen immer häufiger in der Literatur beschrieben.

In dieser Dissertation werden relevante, offene Fragen im Kontext 802.11 p und 802.11 ac Technologien untersucht und Machine Learning Algorithmen verwendet, um den Durchsatz und die Robustheit der Kommunikation zu verbessern.

Um hohen Durchsatz zu erreichen, erlaubt 802.11 ac die Verwendung hoher Bandbreiten. Dennoch führen Letztere zu einer Erhöhung der Variabilität der Kanalzustände über die Frequenz, was die Qualität der Übertragung vermindern kann. Als erster Beitrag präsentieren wir einen Ansatz zum Ausschalten gedämpfter OFDM Unterträger und zur dynamischen Verteilung der Sendeleistung. Für das resultierende Optimierungsproblem untersuchen wir die Leistung und Komplexität der optimalen und verschiedenen suboptimalen Lösungen, teilweise aus der Machine Learning Dömane. Im Allgemeinen liefern die vorgeschlagenen Lösungen eine erhebliche Verbesserung des Durchsatzes.

WLAN basierte Fahrzeugkommunikation wird durch 802.11 p unterstützt, wobei der Fokus auf Anwendungen zur Verbesserung der Verkehrssicherheit gesetzt wird. Obwohl Letztere rechtzeitige und fehlerfreie Übertragungen erfordern, ist es ungewiss, ob die Robustheit von 802.11 p Kommunikationen gegenüber Interferenzangriffen (sogenanntes Jamming) ausreicht. Als zweiten Beitrag charakterisieren wir mittels Messungen den Einfluss von Jamming auf die Leistung der Fahrzeugkommunikation in relevanten Szenarien und zeigen dabei, dass der Erfolg von Verkehrssicherheitsanwendungen schwer beeinträchtigt werden kann. Unsere Beobachtungen motivieren unseren dritten Beitrag, ein Machine Learning basierten Algorithmus zur effizienten Detektion von Jamming Angriffen auf 802.11 Übertragungen. Durch das *Lernen* vom Verhalten ausgewählter Metriken in diversen Szenarien unter dem Einfluss von Jamming wird eine maßgeblich hohe Erkennungsrate der Angriffe erzielt.

Fahrzeuge, die mit 802.11 Technologie ausgestattet sind, können sich mit Access Points verbinden, um Multimedia Anwendungen zu unterstützen. Diese profitieren generell vom hohen Durchsatz, was durch effiziente Algorithmen zur Ratenanpassung erreicht werden kann. Die Mobilität der Fahrzeuge führt zu schnellen Variationen der Kanalbedingungen, wodurch die Auswahl einer adäquaten Rate erschwert wird. Dennoch kann man die Szenario-spezifischen Kommunikationsbedingungen in der Umgebung des Access Points lernen, um diese Aufgabe zu vereinfachen. Unser vierter Beitrag ist ein Machine Learning basierter Algorithmus, der die zeitliche Entwicklung der Signalstärke mit GPS Informationen kombiniert, um zukünftige Kanalbedingungen vorherzusehen und eine passende Senderate auszuwählen.

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