Application

2015-03-31

2015-03922 **Landfeldt, Björn** **NT-14**

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Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

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Project title (english): Performance modelling and access protocols for next generation WiFi

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Keywords: 802.11, medium access control, WiFi, carrier sense multiple access, wireless LAN

Funds applied for

Year:	2016	2017	2018	2019
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Descriptive data

Project info

Project title (Swedish)*

Prestandamodellering och accessprotokoll för nästa generations WiFi

Project title (English)*

Performance modelling and access protocols for next generation WiFi

Abstract (English)*

Despite the widespread use of IEEE 802.11 (WiFi), our theoretical understanding of the behaviour of these networks remains limited. Current models only include edge cases such as saturation traffic and do not adequately model the packet arrival process or collisions during transmission. Our previous results in this area demonstrate that these aspects will have a significant detrimental impact on the performance of wireless LANs due to current trends in the usage and operating conditions of these networks. These trends include increasing raw data rates and changes in traffic patterns towards more real-time and interactive applications. In this project we propose to develop a new analytical model of medium access in 802.11 networks that encompasses these emerging scenarios. A software implementation of the model will be created in order to provide numerical results, which will then be validated using both simulations and real-world experiments. We will also develop novel medium access protocols better suited to address the current challenges in wireless LANs, based on increased cooperation and information sharing between nodes. The new protocols will be implemented in both simulations and an experimental testbed in order to evaluate their performance. In total, the project will run for four years, with an initial period of 18 months for construction of the model, followed by a further 18 months for MAC protocol development and model validation. The model will then be iteratively extended to improve its accuracy and detail. The work on this project will be carried out by Björn Landfeldt and Emma Fitzgerald, working within the networking research group at the Department of Electrical and Information Technology at Lund University.

Popular scientific description (Swedish)*

WiFi har blivit allt vanligare i hem, på arbetsplatser och på offentliga ställen och på det sätt WiFi-nätverk används har samtidigt förändrats. Datahastigheten ökar ständigt med förbättrad teknologi och interaktiva appar som fungerar i realtid, såsom videosamtal, mediaströmning och online datorspel, är nu mycket populära. Dock har vår förståelse för hur enheter i dessa nätverk beter sig inte utvecklats lika snabbt. Vi behöver nya modeller som möjliggör teoretisk analys av trådlösa nätverk under dessa nya, utmanande omständigheter, samt nya protokoll för att enheterna skall klara av att hantera dem. I synnerhet måste enheterna samarbeta i högre grad än de gör idag och våra modeller måste stödja analys av dessa nya protokoll. I detta projekt skall vi skapa en ny modell för accessprotokoll inom WiFi-nätverk för att analysera prestandan inom dessa nätverk, och utveckla nya protokoll fokuserade på samarbete och informationsdelning mellan enheterna.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*	2. Teknik > 202. Elektroteknik och elektronik > 20203. Kommunikationssystem 2. Teknik > 202. Elektroteknik och elektronik > 20206. Datorsystem 2. Teknik > 202. Elektroteknik och elektronik > 20204. Telekommunikation

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

802.11

Keyword 2*

medium access control

Keyword 3*

WiFi

Keyword 4

carrier sense multiple access

Keyword 5

wireless LAN

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

There are no ethical issues that require separate treatment or evaluation for this project.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Modelling and MAC Protocols for Next Generation WiFi Research Programme (Appendix A)

1 Purpose and aims

Today the landscape for wireless LANs is changing dramatically. Peak capacity is no longer king in evaluating the performance of these networks as we are undergoing a fundamental shift in usage patterns. We are moving away from large file transfers and traditional web traffic and towards real-time interactive applications such as video chat, multimedia streaming, and widespread use of social media characterised by frequent but short bursts of information. Our preliminary results in modelling of WLANs demonstrate that with these new traffic patterns, performance degrades substantially, and that this will only be exacerbated by the continual increase in raw data rates with each new release of the WiFi standard. In this project we wish to leverage this new understanding to develop both a new analytical model of WLAN performance and novel, cooperative medium access protocols better suited to meet future network demands.

1.1 An analytical model of wireless LAN medium access

Despite the widespread usage of the IEEE 802.11 family of protocols — WiFi — for more than a decade, our understanding of the behaviour of wireless networks based on these protocols is still very limited. The most widely used model of the 802.11 Distributed Coordination function is that developed by Bianchi [1], which models the network under saturation conditions and does not include packet transmission times. Saturation, in which every node always has a packet available to send, represents only one boundary case of the network behaviour and is not appropriate for today's application mix, where we are seeing an increasing usage of real-time and interactive applications that require unsaturated conditions to perform adequately.

Kleinrock and Tobagi's earlier model [2] captures a much wider range of network behaviour and operating conditions, but was developed for p-persistent carrier sense multiple access (CSMA). Although this protocol also employs carrier sensing as its fundamental mechanism for regulating medium access, it is an earlier and much simpler protocol than 802.11. In p-persistent CSMA, nodes have a fixed probability p to attempt transmission in each timeslot after the channel is vacated by another node. The 802.11 family of protocols do not use p-persistence as their contention-resolution mechanism, but instead define a contention window, the size of which changes as nodes perform exponential backoff in response to collision events. This means that there is a greater dependence on what has previously occurred, resulting in more complex behaviour that requires new modelling.

The aim of this project is to develop a mathematical model of 802.11 medium access that includes not only the key features of the protocol, such as retransmissions and exponential backoff, but that is also applicable under the full range of operating conditions, not just saturation traffic. In particular, packet transmission time should be modelled as our preliminary results demonstrate that the achievable network-wide throughput depends on the ratio of propagation delay to packet transmission time, which is increasing as physical layer data rates improve. This means that both types of packet collisions possible in random-access wireless networks would be included in the model: those from multiple nodes that begin transmissions within a short time of each other, as well as those resulting from nodes choosing the same backoff timer values.

A focus in this work is emerging wireless LAN scenarios, especially those targeted by the ongoing standardisation process for 802.11ax [3], the next version of 802.11 currently in development by the IEEE. These scenarios include a high physical-layer data rate (up to four times greater than the data rate available today); dense, overlapping networks, potentially with many different operators; and many small packets being transmitted, in both an uplink and downlink direction. The increase in data rate, along with the abundance of small packets, means that the propagation delay and overheads such as interframe spacing have a much greater effect on network performance. Since our model will include sub-saturation conditions and packet transmission time, it will capture these effects and provide more reliable performance estimates than the existing models.

1.2 Cooperative MAC protocols for wireless LANs

In order to address the emerging scenarios for wireless LANs outlined above, we forsee the need for increased information sharing and cooperation between nodes in order to perform medium access control. The basic mechanism of CSMA, that is, channel sensing, provides information of decreasing quality as the propagation delay increases relative to the packet transmission time. To avoid an accompanying degradation in performance, this information must be augmented in order for contending nodes to make good decisions about when to transmit without incurring collisions. However, this should be done without breaking backward compatibility with existing 802.11 systems. We therefore propose to design new, cooperative MAC protocols for wireless LANs which will operate as an extra, information sharing and cooperation layer on top of 802.11. The numerical results and understanding of network behaviour obtained from our analytical model will be used to inform the design of these protocols, giving insight into how much and which information must be exchanged in order to cooperatively control channel access.

2 Survey of the field

2.1 Modelling of CSMA in wireless LANs

Kleinrock and Tobagi developed a model in [2] for analysing the throughput and delay characteristics of a number of CSMA variations. A number of simplifying assumptions are made in the model in order to make the analysis tractable. In particular a common packet size and propagation delay across all nodes is used, and the network consists of an infinite number of nodes collectively forming a Poisson-distributed packet arrival process. The model is extended to analysis using a finite number of nodes in [4]. While this model does not address the complexities of the 802.11 Distributed Coordination Function (DCF), it does cover the full range of operating conditions and demonstrates a methodology that can be used as the starting point for a model of protocols in use today.

Bianchi's model [1] uses two-dimensional Markov chains to describe the behaviour of a node executing the 802.11 DCF, where each state represents the node's backoff counter — the number of timeslots it will wait before next attempting transmission. It has been particularly influential, with numerous further developments following on from it [5–10]. The Bianchi model captures the behaviour of 802.11 when the network is at saturation, that is, when every node always has a packet queued for transmission. As state transitions occur when the backoff counter changes, the time elapsed between different states is not modelled directly. In particular, there is no notion of packet transmission time, since at saturation the packet arrival rate does not need to be considered and the node's backoff counter never changes while a transmission is in progress. Collisions, when two or more nodes attempt to transmit simultaneously, resulting in interference, are also only modelled when nodes choose the same backoff counter value. This ignore the case where nodes sense the channel during one propagation delay after the beginning of a packet. In addition, a constant collision probability is used, which is not the case in reality.

2.2 Trends in wireless LANs

There are two main changes occurring in wireless LANs that affect the performance of CSMA-based protocols. The first is increased raw data rates, leading to shorter frame transmission times. The second change we are seeing is an increased number of short packets, which incur higher proportional overhead. Carrier-sensing is vulnerable to collisions whenever a node senses the channel state within one propagation delay of the beginning of another node's transmission. This becomes increasingly likely as data rates increase and packet sizes decrease, since the proportion of transmission time represented by periods vulnerable to incorrect sensing (and thus collision) increases. Data rates have increased with successive versions of the 802.11 standard and 802.11ax seeks to continue this trend, with a target of at least a four times increase in data rate [3].

In many of today's applications, a high number of small packets are generated [11], and this carries through to lower layers. A recent study of packet sizes in 802.11 networks in Boulder, Colorado shows a large proportion of small packets being transmitted [12]. In both residential and managed enterprise environments, packets of less than 300 bytes predominated. Moreover, usage patterns in wireless LANs are changing, with increases in uplink traffic from many different nodes; real-time, delay-sensitive traffic; and low-frequency sensor traffic such as that needed for smart homes and the Internet of Things [11, 13–17]. These traffic types do not lend themselves well to frame aggregation and as our preliminary results show, CSMA is inherently unsuited to networks in which packet transmission times are short, as is the case with high data rates and small packets.

2.3 Cooperative MAC protocols

A range of approaches to including some amount of cooperation and/or coordination between nodes for medium access control have been investigated. Many of them demonstrate performance improvements over standard 802.11, however these protocols are either not based on 802.11 and thus do not allow backwards compatibility with existing systems, or else lack the solid theoretical grounding we seek to achieve with the model we will develop in this project. Some particular strategies that have been tried include link scheduling, frame scheduling and resource reservation.

There is significant existing work dealing with distributed link scheduling in wireless networks. Here, links are scheduled to be utilised at particular times, usually based on the traffic or energy requirements of the nodes involved, with regard to interference metrics between different links [18–22]. While beneficial if all nodes participate, this approach is not compatible with legacy 802.11 nodes, which are unaware of the link scheduling agreed upon by the other nodes.

In [23] the authors propose a distributed scheduling algorithm based on the 802.11 DCF. As such, this protocol uses a similar collision avoidance mechanism to that employed by the 802.11 DCF, that is, randomised backoff counters. This means that collisions are still possible and increasingly likely as the offered load increases. The cooperative scheduling protocol presented in [24] does, on the other hand, achieve perfect, collision free scheduling. However, for a wireless network with potentially high mobility and node turnover, this protocol has the drawback that establishing a schedule takes a number of rounds and thus significant time. Once established, the schedule is then inflexible and cannot be changed without restarting the entire process.

There is also previous work focusing on reservation of resources in wireless networks, including distributed reservation [25–28]. The proposed solutions often require negotiation and/or acknowledgement between nodes. This a reasonable approach when the aim is to ensure a minimum resource allocation to meet an application's quality of service requirements, but binding reservations of this kind may result in wasted resources if a reservation is not fully used. Resource reservation also does not allow devices running legacy 802.11 variants to interact gracefully with the system, since all nodes must agree to and abide by these reservations.

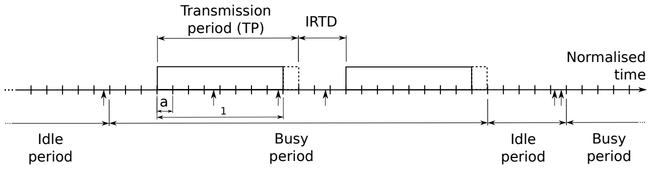


Figure 1: *p*-persistent CSMA cycle as described in [2]. Vertical arrows indicate packet arrivals.

3 Project description

The project will begin with a deeper investigation of the challenges currently facing CSMA-based protocols caused by increasing data rates and changing traffic patterns. We will examine the information quality obtained through channel sensing and how this is affected by these trends. Using this understanding, we will next optimise the performance of current 802.11 systems within the bounds of the existing protocol.

The primary focus of the project, however, will be on the development of a new model of 802.11 networks. This will follow a similar methodology to that used by Kleinrock and Tobagi in [2] but will require new analysis to account for the complexities of the 802.11 protocol, in particular exponential backoff and retransmissions. We will verify the validity of the model through both simulation studies and real-world experiments. We will then develop and implement new cooperative medium access protocols for wireless LANs. The design of these protocols will be informed by the results obtained from our model.

3.1 Theory

Our approach to modelling the performance of 802.11 networks will be based upon that used by Kleinrock and Tobagi in [2]. We therefore give here an overview of this model. The *p*-persistent CSMA protocol as described in [2] follows a cycle consisting of an idle period followed by a busy period (see Figure 1). During an idle period, no packets are transmitted on the channel and no nodes have packets queued to send. An idle period ends when a packet arrives at a node ready to be transmitted. The system then enters a busy period. Note that during a busy period, the channel itself is not constantly busy, that is, a signal is not present on the channel the entire time. This is because some of the time is spent with nodes waiting to transmit, according to the persistence scheme.

A busy period consists of a number of transmission periods (TPs) in which nodes attempt to transmit packets. Each transmission can either be successful, or result in a collision, in which case the packet is scheduled for retransmission. A TP ends one propagation delay (denoted by a) after the end of the actual transmission. At the end of a TP, the system enters an initial random transmission delay (IRTD) while nodes perform the *p*-persistence backoff protocol, after which a new TP begins. Once no nodes have packets queued to send, the system once again enters an idle state, concluding the cycle.

Starting from the stochastic packet arrival process, Kleinrock and Tobagi derive expressions for the probability distributions of the number of TPs in a busy period, the length of an IRTD, and finally the time spent in busy and idle periods. This then allows performance metrics such as normalised throughput and average delay to be calculated.

3.2 Methodology

3.2.1 Information Quality in CSMA

In order to understand the challenges posed to CSMA-based protocols by increasing data rates and changing traffic patterns in wireless LANs, we propose to first use the Kleinrock and Tobagi model to investigate the quality of the information that can be obtained from channel sensing at high values of a. We will do this by taking the correlation between the true channel state — that is, whether or not any node is actually transmitting — and the channel state as sensed by another node, taking into account errors caused by the propagation delay. This will then provide further insight into the performance issues faced by CSMA as well as an understanding of the limits for the performance of CSMA-based protocols.

3.2.2 Optimising 802.11

Although it is anticipated that the model developed in this project will be used to design new MAC protocols, it is nonetheless important to consider the performance of those currently widely used, that is, existing variants of 802.11. To this end, we will use our analysis of p-persistent CSMA to inform the selection of contention window parameters in 802.11. The model in [2] allows us to determine the optimal value of p for a given offered load and value of a. By comparing the backoff time distributions of nodes under p-persistent CSMA and the 802.11 DCF, we will derive an equivalency between this optimal p value and the minimum and maximum values of the contention window.

3.2.3 Creating the model

In order to develop a more complete model of the 802.11 DCF that includes transmission time and propagation delay, we propose to begin by following a similar methodology to that used in [2]. This means examining the cycle of busy and idle channel states in terms of the probabilities of nodes transmitting or not transmitting, and for how long. From this, we would then derive an expression for throughput by finding the proportion of time the channel spends transmitting useful data, as opposed to time it spends transmitting protocol overhead, idle, or during packet collisions when data is lost.

We need to make some simplifying assumptions in order to make the analysis more tractable, with the aim of later extending the model by relaxing these assumptions once an initial model has been developed. First, we will assume time is broken up into discrete timeslots and that packet transmission always begins at the start of a slot. These timeslots may not necessarily be the same length of a slot as defined in the 802.11 standard — in fact in order for the model to produce realistic results they will need to be significantly shorter.

We will analyse the system behaviour in terms of busy and idle states. To do this, we will first determine the probability distribution of the number of successive transmissions until no node has any packets remaining in its queue to be sent, and thus the total time the system is in a busy state. Once no nodes have packets waiting to send, the system returns to an idle state. The length of time spent in an idle state can be derived directly from the traffic arrival distribution.

Together, the time spent in a busy period plus the time spent in the following idle period form one cycle of the system. Within this cycle, the proportion of the time that will be spent transmitting useful data depends on the probability of a collision during each transmission period and the total number of transmission periods in the busy period. The ratio of this time spent transmitting useful data to total time in the cycle then gives the throughput of the network, normalised to the total channel capacity. While a specific value cannot be determined for any given cycle, we will use the probability distributions described above to determine the mean and variance for this ratio over a long period of time. Other metrics such as average delay or jitter will be derived using a similar methodology.

3.2.4 Model implementation

Expressions for throughput, delay and other metrics of interest produced from this modelling methodology are likely to be intractable. We will therefore construct a numerical solution in order to obtain performance results. Key considerations here are the convergence of the expressions to be implemented, processing time and the range of values that can be supported. While the implementation of the model is not anticipated to form a particularly challenging part of the project, the computational feasibility of the resulting calculations should be considered whilst developing the analytical model.

3.2.5 Model validation

Once the model has been developed and implemented so that numerical results can be produced, it must also be validated for correctness. This will be done through both simulations and experiments with real hardware. Both of these approaches have advantages and disadvantages and thus a combination of the two is most desirable. Experiments on real hardware will produce the most accurate and realistic results to compare to the model, however simulations allow a large range of different scenarios to be tested and input parameters to be easily controlled.

3.2.6 Cooperative MAC protocols

From the model we develop, we will obtain an increased understanding of the behaviour of CSMA-based MAC protocols and will then leverage this to design new MAC protocols more suited to emerging scenarios in wireless LANs. These protocols will involve greater cooperation and information sharing between nodes to offset the unreliability of information obtained from channel sensing when packet transmission times become short relative to the propagation delay. Key considerations will be to maintain backwards compatibility with existing 802.11 protocols and to preserve their advantages, in particular that they are decentralised and require minimal to no configuration on the part of the operator.

These goals will be achieved by maintaining the CSMA mechanism and the basic 802.11 distributed coordination function at the point of actual packet transmission, whilst adding new information sharing mechanisms over the top. By participating in the DCF, nodes running the new, cooperative protocols will be able to inter-operate fairly with legacy 802.11 nodes. However, these new nodes will exchange information with each other, allowing them to make more intelligent decisions about when to transmit.

This may include, for example, information about current traffic load and characteristics (such as application type or traffic distribution), network topology, or mobility patterns. There are a range of strategies that can be implemented which result in varying overhead and tightness of coupling between different nodes. The results from our modelling will inform what is the appropriate level and type of information to exchange to gain the best trade-off between overhead incurred and performance gain from the use of the new information.

3.3 Timetable

Task	Duration	Start	End
Study of information quality in CSMA and optimisation of 802.11	6 months	January 2016	June 2016
Development and validation of initial model	18 months	January 2016	June 2017
Development and testing of cooperative MAC protocols	18 months	July 2017	January 2019
Iterative extension of model	18 months	January 2018	June 2019
Simulation studies of model extensions	12 months	January 2019	December 2020

3.4 Project organisation

Björn Landfeldt will lead the project, with work in the project also carried out by Emma Fitzgerald. We are working within the Networking research group at the School of Electrical and Information Technology at Lund University. Results produced from the model developed in this project will likely be of use in some of our other, related research projects and as such the model will be developed and tested in consultation with others in the group.

3.5 Execution

We will create the software implementation of our model using Python and NumPy [29] in order to obtain numerical results for metrics such as throughput and delay. For validation of the model and implementation of the cooperative MAC protocols, we will need to perform simulations. This will be done using the ns-3 simulator [30]. We will then use Akaroa [31] to parallelise the simulations, which we will run on our existing simulation cluster.

We will carry out our experimental studies using the Wireless MAC Processor [32]. This enables rapid development of new MAC protocols which can then be written to the firmware of wireless network interface cards. This framework supports cards using Broadcom SoftMAC chipsets, with the b43 driver for Linux. We will therefore set up an experimental testbed using these cards.

4 Significance

4.1 The place of wireless LANs in the communications landscape

Wireless LANs are widely used already in homes, businesses and public places. With the move towards 5G systems, capacity in cellular networks is increasing, but will not replace the need for wireless LANs in the future. Not only do WLANs provide the higher bandwidth needed for more demanding applications, but they also play a crucial role in 5G systems by allowing for offloading from cellular basestations to wireless LANs in areas of high demand. WLANs are therefore a key technology in the future landscape of wireless networking.

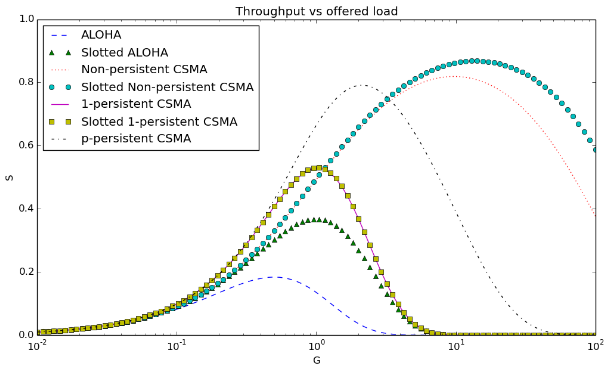
4.2 Changing usage of wireless LANs

As discussed in section 2.2, usage patterns in wireless LANs are shifting towards a higher proportion of small packets and a different application mix, with a particular focus on real-time and interactive applications as well as social media. We therefore need to develop the analytical tools to understand the performance of wireless LANs under these conditions.

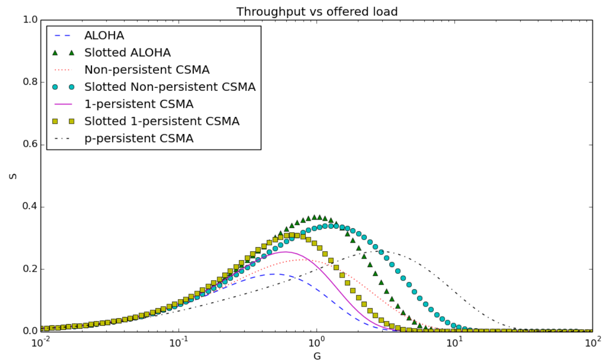
4.3 802.11ax: The next WiFi standard

The IEEE is in the early stages of developing the next version of 802.11: 802.11ax High Efficiency WiFi. The importance of MAC layer performance has been identified by the IEEE 802.11ax task force. Until now, the focus has been on the physical layer, particularly with the introduction of MIMO. Some key features of 802.11ax are a target 4x increase in data rate and the use of WiFi in high-density, overlapping networks. Example scenarios include a high-rise apartment building in which each apartment has its own wireless LAN and a stadium scenario in which thousands of users attempt to access a wireless LAN within a small geographic area.

These scenarios represent a further departure from traditional WLAN modelling. The increased data rate means that packet transmission times will decrease accordingly, further exacerbating the problem of small packets, which our preliminary work in this area has explored and which has severe consequences for the performance of CSMA-based MAC protocols. A high number of nodes within a small area also poses significant challenges for CSMA as collisions become increasingly likely and bandwidth is thus wasted on unsuccessful transmissions.



(a) Throughput vs offered load for various wireless MAC protocols, $a = 0.01$



(b) Throughput vs offered load for various wireless MAC protocols, $a = 0.5$

4.4 Future wireless MAC protocols: cooperation and information sharing

In order to achieve the data rate increase required by 802.11ax and tackle the challenges facing CSMA, nodes require better quality information when making decisions about when to transmit. An important mechanism to achieve this is by increasing cooperation and information sharing between nodes. The design of future MAC protocols incorporating such features must be grounded in trustworthy analysis in order to adequately determine their performance under a range of operating conditions.

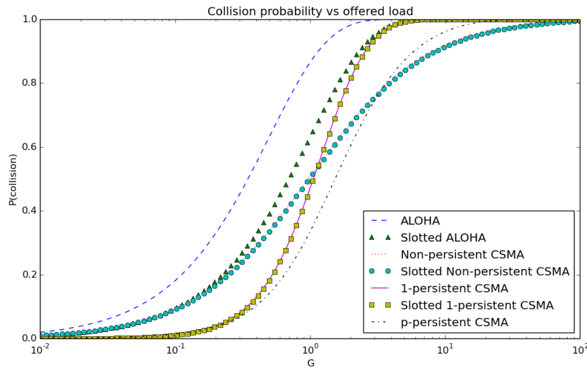
5 Preliminary results

In the modelling results presented in [2], only results for relatively small values of the propagation delay, a, are given. In [33], we developed a software implementation of the model from [2] and provided analysis for larger values of a. Figures 2a and 2b show throughput versus offered load for the various MAC protocols examined, with decreasing a values. A value of $p = 0.1$ is shown for p-persistent CSMA but the results were similar for other p values. As can be seen in the figures, as a grows larger, throughput decreases dramatically, eventually to the point that the CSMA protocols perform worse than the slotted ALOHA protocol — that is, we eventually gain nothing by sensing the channel and can do no better than pure random access.

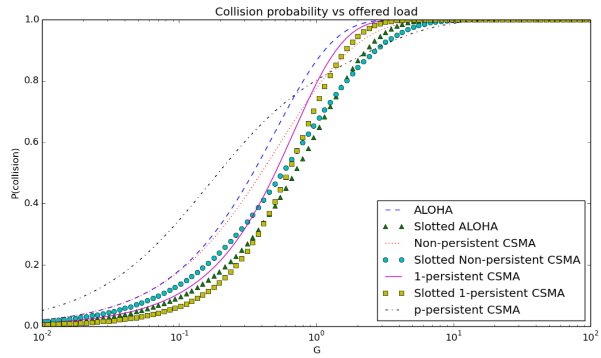
To understand why this is the case, we examined the probability that there will be a collision when a node attempts to transmit a packet. Figures 3a and 3b show the collision probability as a function of offered load for the same values of a as in Figures 2a and 2b, again with $p = 0.1$. We see that the probability that a packet will encounter a collision using CSMA increases as a increases, eventually becoming greater than that for slotted ALOHA. More time is thus wasted transmitting interfering packets that do not result in data being received successfully, reducing the channel utilisation.

Moreover, the values of a at which the failure of CSMA occurs are realistic in wireless LANs today or in the near future. Figure 4 shows the maximum (normalised) throughput of p-persistent CSMA, for a variety of network diameters, packet sizes and data rates. Today, with 802.11ac, a data rate of 500Mb/s is achievable and as can be seen in the figure, the maximum achievable throughput is poor — even below slotted ALOHA — at small packet sizes.

These results demonstrate that we need to develop a better understanding of wireless LAN medium access protocols under a wide range of operating conditions in order to meet the needs of future networks. We can also see that the utility of CSMA as the sole mechanism for arbitrating medium access will be limited in these networks and this necessitates the development of new MAC protocols with a greater emphasis on information sharing and cooperation.



(a) Collision probability for various wireless MAC protocols, $a = 0.01$



(b) Collision probability for various wireless MAC protocols, $a = 0.5$

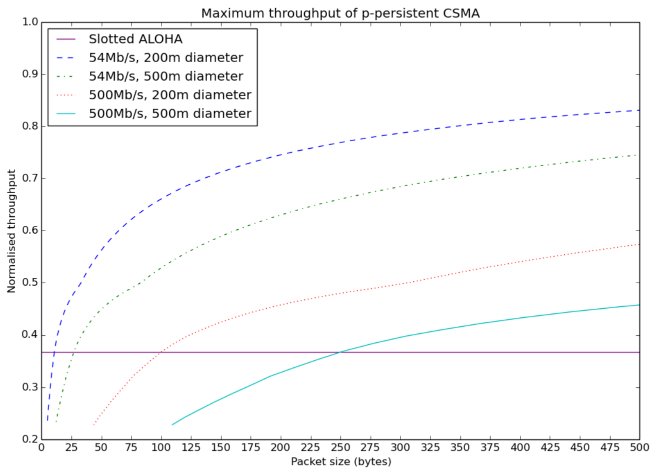


Figure 4: Maximum throughput of p-persistent CSMA for different data rates, network diameters and packet sizes

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Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Björn Landfeldt	
2	Participating researcher	Emma Fitzgerald	

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Participating researcher	Emma Fitzgerald	42	410,735	422,776	436,155	449,534	1,719,200
2	Applicant	Björn Landfeldt	20	327,786	338,489	347,854	358,557	1,372,686
	Total			738,521	761,265	784,009	808,091	3,091,886

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Office space, lab, general premises	76,000	77,000	79,000	81,000	313,000
	Total	76,000	77,000	79,000	81,000	313,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Travel costs	Conference fees, tickets, per diem expenses	60,000	60,000	60,000	60,000	240,000
2	Equipment	Computer accessories, components	10,000				10,000
	Total		70,000	60,000	60,000	60,000	250,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	738,521	761,265	784,009	808,091	3,091,886		3,091,886
Running costs	70,000	60,000	60,000	60,000	250,000		250,000
Depreciation costs					0		0
Premises	76,000	77,000	79,000	81,000	313,000		313,000
Subtotal	884,521	898,265	923,009	949,091	3,654,886	0	3,654,886
Indirect costs					0		0
Total project cost	884,521	898,265	923,009	949,091	3,654,886	0	3,654,886

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

We are applying first and foremost for coverage for the time we will dedicate to the project. The level is set such that the project can be carried out within the prescribed time. Aside from salary costs we are applying for financing to cover the establishement of an experimental testbed. Since the research problems we are investigating concern a complex system with many variables, it is of the highest importance that we are able to verify our modelling as fundamentally as possible. The simulation studies we will carry out have the advantage of being easily scalable to large system scenarios but at the same time the simulation models abstract away certain parameters. Our experiments will therefore complement our simulation studies as independent tests can be carried out. We therefore seek financing for access points that can be programmed to test our developed algorithms.

The project will generate a number of publications per year. Within wireless network modelling there are, aside from leading journals, also numerous trendsetting conferences where it is important to disseminate results for the highest impact within this research area. We are applying for funds to publish and take part in these conferences during the project.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019

CV and publications

CV

Curriculum Vitae

Bjorn Landfeldt, 670825-0193

Education	
Bachelor of Engineering (equivalent)	
Royal Institute of Technology (KTH)	1996
PhD in Telecommunications	
University of New South Wales, Australia	
Thesis Title: “Reactive Quality of Service Management from an End-User Perspective”	
Supervisor, Prof. Aruna Seneviratne	2000
Employment	
Current Employment:	
Professor in Network Architecture and Services	
Department of Electrical and Information Technology	
Lund Institute of Technology	2012-
Scientific Leader and Director, MAPCI	2014-
Previous Employments:	
Associate Professor	
School of Information Technologies	
The University of Sydney, Australia	2001-2012
Senior Researcher	
Ericsson Research, Networks and Systems	
Kista, Stockholm	2000-2001
Completed PhD students, primary Supervisor	
Sanchai Rattananon	2005
Apichan Kanjanavapastit	2005
Kaychalya Premadasa	2007
Khaled Matrouk	2008
Mohsin Iftikhar	2008
Daniel Cutting	2008
Suparerk Manitpornsut	2009
Saeed Bastani	2013
Emma Fitzgerald	2013
Quincy Tse	2014
Post Doctoral supervision:	
Jahan Hassan	2005-2007
Riky Subrata	2005-2007
Zainab Zaidi	2007-2009
Zhi Zhang	2015-
Mehmet Karaca	2015-

Evidence of Leadership and Impact in the Field
I am currently an associate editor of Journal of Communications, and Journal of Pervasive Computing and Communications. I have also been a Guest Editor for several special issues of Journal of Parallel and Distributed Systems, and Computer Communications.
However, in the networking field (as in most computer science fields), conferences play a role as important as journals where the leading conferences typically have an acceptance rate between 10 and 30% and employ a rigorous review process. I have had the following leading roles in conferences:

Conference Program Chairing

1) ACM MSWIM 2012 (Co-Chaired with Ravi Prakash)
2) ACM MSWIM 2011 (Co-Chaired with Luciano Bononi)
3) ACM International Symposium on Mobility Management and Wireless Access, MobiWac, Bodrum Turkey, Oct. 2010
4) ACS/IEEE International Conference on Computer Systems and Applications, AICCSA 2010 (Co-Chaired with Stephan Olariu)
5) IEEE ICCCN Symposium on Network Architectures and Protocols (Co-Chaired with Joe Touch) San Francisco, USA 2009
6) ACM International Symposium on Mobility Management and Wireless Access, MobiWac, Teneriffe, Canary Islands, 2009.
7) IEEE ICCCN Symposium on Protocols and Algorithms for Wireless Networks, (Co-chaired with Lavy Libman) Virgin Islands, USA, 2008
8) ACM International Symposium on Mobility Management and Wireless Access, MobiWac, Vancouver, Canada, 2008.
9) ACORN Workshop on Underwater Networks, Adelaide, Australia, 2007
10) IEEE International Conference on Networking – ICON, (Co-chaired with Tim Moors) Sydney, Australia, 2003

Recent Conference Program Committee Memberships

1) IEEE WCNC 2005, 2006, 2010, 2011
2) IEEE ICC 2005, 2006, 2007, 2008, 2009, 2011
3) IEEE WIOPT 2010, 2011
4) International Symposium on Smart Home, SH 2010
5) IEEE VON 09
6) IEEE and ACM FMN 2009
7) UIC 2009

In Australia I am widely considered to be a leader of my field. I was hired as the technical expert consultant to give policy advice to the Department of Broadband, Communications and the Digital Economy on the widely publicised study on the feasibility of implementing mandated Internet filtering at the ISP level. In addition, I have acted as an expert witness before a parliamentary hearing in Canberra by the Select Joint Committee on Cyber-Safety. I have further appeared on over 50 TV, Radio and Newspaper interviews over the past few years, both in Australia and Internationally. I was also invited by the dean, Faculty of Information and Communication Technologies at Swinburne University as technical expert and reviewed the research performance of the Centre for Advanced Internet Architectures (CAIA) in 2010.

Curriculum Vitae

Emma Fitzgerald

1 Högskoleexamen (Higher education qualification(s))

2008 BE (Computer), Hons I, University of Sydney
2008 BSc (Advanced Mathematics), University of Sydney

2 Doktorsexamen (Doctoral degree)

2013 PhD (Computer engineering), University of Sydney
Avhandlingens titel: Achieving dynamic road traffic management by distributed risk estimation in vehicular networks
Handledare: Björn Landfeldt

3 Postdoktorsvistelser (Postdoctoral positions)

2014-2015 Institutionen för Elektro- och informationsteknik, Lunds universitet

4 Docentkompetens (Qualification required for appointments as a docent)

5 Nuvarande anställning (Current position)

Förordnandetid: Januari 2014
Andel forskning: 83%

6 Tidigare anställningar (Previous positions and periods of appointment)

2013 Research Assistant, Computer-Human Adaptive Interaction research group, School of Information Technologies, University of Sydney
2009–2013 Tutor, School of Information Technologies, University of Sydney
2007–2012 Tutor, School of Electrical and Information Engineering, University of Sydney
2009 Tutor, The Womens College
2008–2009 Vacation Scholar, Computer-Human Adaptive Interaction research group, School of Information Technologies, University of Sydney
tabletop computer
2007–2008 Vacation Scholar, Autonomous Systems Laboratory, Commonwealth Science and

Industrial Research Organisation (CSIRO)

2006–2007 Vacation Scholar, Computer-Human Adaptive Interaction research group, School of Information Technologies, University of Sydney

2006 Research assistant, Computing and Audio Research Laboratory, School of Electrical and Information Engineering, University of Sydney
Indoor location tracking in wireless sensor networks.

7 Uppehåll i forskningen (Interruption in research)

8 Handledning (Supervision)

9 Eventuell övrig information av betydelse för ansökan. (Other information of relevance to the application)

Publication list

APPENDIX C, Publication List

Björn Landfeldt, 670825-0193

The citation counts for the following publication list has been collected using Google Scholar. The list comprises publications since 2007 (8 years).

Refereed Journal Articles

- *"Fair Flow Rate Optimization by Effective Placement of Directional Antennas in Wireless Mesh Networks", Y. Li, M. Pioro and B. Landfeldt, Performance Evaluation 2015, doi: 10.1016/j.peva.2015.01.007 in print.
- "Interarrival Distribution of a Long-Range Dependent Workload Process", M. Caglar, M. Iftikhar and B. Landfeldt, Applied Mathematics and Information Science 8, no 1L, pp. 15-26 (2014)
- "On the Provisioning of QoS Mapping in Cellular and IP Networks Using a Translation (Function) Matrix", M. Iftikhar, W. Al-Salih, I. Shoukat, M. Uddin, M. Talha, B. landfeldt and A. Zomaya, Information, (06) 2012.
- "Improving Densely Deployed Wireless Network Performance In Unlicensed Spectrum through Hidden-Node Aware Channel Assignment", S. Manitpornsut, B. Landfeldt and A. Boukerche, Performance Evaluation, Volume 68, Issue 9, September 2011, pp. 825-840. Number of citations: 2
- "Service level agreements (SLAs) parameter negotiation between heterogeneous 4G wireless network operators", M. Iftikhar, B. Landfeldt, S. Zeadally and A. Zomaya, Pervasive and Mobile Computing, Volume 7, Issue 5, 2011, pp. 525-544. Number of citations: 13
- "Real-time detection of traffic anomalies in wireless mesh networks (WMN)", Z. Zaidi, S. Hakami, B. Landfeldt and T. Moors, Wireless Networks, Volume 16, No. 6, pp. 1675-1689, August 2010. Number of citations: 7
- "Cooperative Power-Aware Scheduling in Grid Computing Environments", R. Subrata, A. Y. Zomaya and B. Landfeldt, Journal on Parallel and Distributed Systems, vol. 70. Issue 2, 2010. Number of citations: 45
- "Special Interest Messaging: A Comparison of IGM Approaches", D. Cutting, A. Quigley and B. Landfeldt, The Computer Journal 53 (1) 2010, pp. 50 - 68. Number of Citations: 4
- "Detection and Identification of Anomalies in Wireless Mesh Networks using Principal Component Analysis", Z. Zaidi, S. Hakami, T. Moors and B. Landfeldt, Journal of Interconnection Networks, Vol. 10, no. 4 (2009) pp. 515-532. Number of citations: 4
- "Towards the Formation of Comprehensive SLAs between Heterogeneous Wireless DiffServ Domains", M. Iftikhar, B. Landfeldt and M. Caglar, Springer Telecommunication Systems special issue on Wireless networks Modeling, vol. 42, issue 3-4, December 2009. Number of citations: 15
- "Prolonging the System Lifetime and Equalizing the Energy for Heterogeneous Sensor Networks Using RETT Protocol", K. Matrouk and B. Landfeldt, International Journal of Sensor Networks, vol. 6, no. 2, 2009. Number of citations: 9

- "RETT-gen: A globally efficient routing protocol for wireless sensor networks by equalising sensor energy and avoiding energy holes", K. Matrouk and B. Landfeldt, Elsevier Journal on AdHoc Networks, Vol.7 no. 3, May 2009, pp. 514-536. Number of citations: 40
- *"Weighted Channel Allocation and Power Control for Self-Configurable Infrastructure WLANs" , S. Manitpornsut and B. Landfeldt, Journal of Interconnection Networks, Vol. 9, No. 3 2008, pp. 299-316. Number of citations: 3
- *"A Cooperative Game Framework for QoS Guided Job Allocation Schemes in Grids", R. Subrata, A. Y. Zomaya and B. Landfeldt, IEEE Transactions of Computers, vol. 57 no. 10, 2008, pp. 1413-1422. Number of citations: 51
- "Monitoring Assisted Robust Routing in Wireless Mesh Networks" Z. R. Zaidi and B. Landfeldt, ACM/Springer Mobile Networks and Applications (MONET), vol.13, issue 1-2, April 2008, pp. 54-66. Number of citations: 9
- "Multiclass G/M/1 Queueing System with Self-Similar Input and Non-Preemptive Priority", M. Iftikhar, M. Caglar and B. Landfeldt, Journal of Computer Communications, vol. 31, issue 5, 2008, pp. 1012-1027. Number of citations: 25
- "SPICE: Scalable P2P Implicit Group Messaging", D. Cutting, B. Landfeldt and A. Quigley, Journal of Computer Communications Special issue on Foundation of Peer-to-Peer Computing, Vol. 31 (3), 2008, pp. 437-451. Number of citations: 9
- "Trust-Based Fast Authentication for Multiowner Wireless Networks", J. Hassan, H. Sirisena, B. Landfeldt, IEEE Transactions on Mobile Computing, vol. 7, no. 2, 2008, pp. 247-261. Number of citations: 25
- "Special interest messaging: A Comparison of IGM Approaches", D. Cutting, A. Quigley and B. Landfeldt, The Computer Journal, Oxford Press, Published online December 2007, DOI 10.1093/comjnl/bxm076. Number of citations: 4
- "Experiences in Deploying a Wireless Mesh Network Testbed for Traffic Control", Z. Wang, K.Lan , R. Berriman, T. Moors, M. Hassan, L. Libman, M. Ott, B. Landfeldt, Z. R. Zaidi and A. Senevirate, ACM SIGCOMM Computer Communications Review, vol. 37 (5), 2007, pp. 17-28. Number of citations: 21
- "A Game Theoretic Approach for Load Balancing in Computational Grids", R. Subrata, A. Zomaya and B. Landfeldt, IEEE Transactions on Parallel and Distributed Systems, vol. 19, no. 2, 2007, pp 1-11. Number of citations: 78
- "Artificial Life Techniques for Load Balancing in Computational Grids", R. Subrata, A. Zomaya and B. Landfeldt, Elsevier Journal of Computer Sciences and Systems Special Issue on Network Based Computing, vol. 73, Issue 8, 2007, pp. 1176–1190. Number of citations: 46

Refereed Conference Publications

- "Towards Optimal Content Replication and Request Routing In Content Delivery Networks", P. Amani, S. Bastani and B. Landfeldt, In Proc. IEEE ICC 2015, London, England June 2015, to Appear.
- *The failure of CSMA in emerging wireless network scenarios, E. Fitzgerald and B. Landfeldt, In Proc. IFIP Wireless Days, Rio de Janeiro, Brazil, Nov. 2014.

- “Improving minimum flow rate in wireless mesh networks by effective placement of directional antennas”, Y. Li, M. Pioro and B. Landfeldt, In Proc. ACM MSWIM, Barcelona Spain Nov. 2013 Number of citations: 1
- “On Road Network Utility Based on Risk-Aware Link Choice”, E. Fitzgerald and B. Landfeldt, In Proc. IEEE Intelligent Transport Systems Conference (ITSC), The Hague, Netherlands October 2013
- “Trading Accuracy and Resource Usage in Highly Dynamic Vehicular Networks”, E. Fitzgerald and B. Landfeldt, IEEE Intelligent Transport Systems Conference (ITSC), The Hague, Netherlands October 2013
- “The Implementation of Novel Idea of Translation Matrix to Maintain QoS for a Roaming User Between Heterogeneous 4G Wireless Networks”, M. Iftikhar, M. Zuair, A. Rahal, M. Rahal, J. Taheri, A. Zomaya and B. Landfeldt, in Proc. IEEE P2MNET, Clearwater, Fl; USA, October 2012.
- “A Social Node Model for Realising Information Dissemination Strategies in Delay Tolerant Networks”, S. Bastani, B. landfeldt, C. Rohner and P. Gunningberg, In Proc. ACM MSWIM 2012, Paphos, Cyprus Oct. 2012. Number of citations: 5
- “A System for Coupled Road Traffic Utility Maximisation and Risk Management Using VANET”, E. Fitzgerald and B. Landfeldt, In Proc IEEE ITSC, Anchorage, USA, Sept. 2012, Number of citations: 7
- “Interference-Aware Geocasting for VANET”, Q. Tse and B. Landfeldt, VTP 2012, In Proc. IEEE WoWMoM 2012. Number of citations: 3
- “On the Reliability of Safety Message Broadcast in Urban Vehicular Ad hoc Networks”, S. Bastani, B. Landfeldt and L. Libman, in Proc. ACM MSWIM, Miami, FL, USA, October 2011. Number of citations: 8
- *“A Traffic Density Model for Radio Overlapping in Urban Vehicular Ad Hoc Networks”, S. Bastani, B. Landfeldt and L. Libman, in Proc. IEEE LCN 2011, October 2011. Number of citations: 11
- "Privacy preserving neighborhood awareness in vehicular ad hoc networks", Osama Abumansoor, Azzedine Boukerche, Bjorn Landfeldt, Samer Samarah, Proceedings of the 7th ACM symposium on QoS and security for wireless and mobile networks, Miami FL, USA October 2011. Number of citations: 1
- “Reducing Handoff Latency for WiMAX Networks using Mobility Patterns”, Z. Zhang, A. Boukerche and B. Landfeldt, IEEE WCNC, Sydney Australia, April 18-21 2010. Number of citations: 9
- “Efficient Channel Assignment Algorithms for Infrastructure WLANs Under Dense Deployment”, S. Manitpornsut, B. Landfeldt and A. Boukerche, ACM MSWIM, Tenerife Spain, October 2009. Number of citations: 9
- Performance Evaluation of Opportunistic temporal-Pairing Access Network (OPAN), L Wu, R, Hsieh and B. Landfeldt, Chinacom 2009, Xi’An, China, Aug. 26-28 2009.
- “The Problem of Placing Mobility Anchor Points in Wireless Mesh Networks”, L. Wu and B. Landfeldt, ACM Mobiwac, Vancouver, Canada, October 2008. Number of citations: 5

- “Interarrival time distribution for a non-Markovian arrival process”, M.Caglar, M. Iftikhar and B. Landfeldt, in Proc. Association of European Operational Research Societies (EURO) Working Group on Stochastic Modeling, Istambul, Turkey June 2008.
- “Detection and identification of anomalies in wireless mesh networks using Principal Component Analysis (PCA)”, S. Hakami, Z. R. Zaidi, B. Landfeldt and T. Moors. in Proc. ISPAN, Sydney, Australia, 2008, Invited paper. Number of citations: 8
- "Monitoring assisted robust routing in wireless mesh networks", Z. R. Zaidi and B. Landfeldt, in Proc. IEEE/ACM MASS, Pisa, Italy, October, 2007. Number of citations: 8
- “Traffic Engineering and QoS Control between Wireless DiffServ domains using PQ and LLQ”, M. Iftikhar, M. Caglar, B. Landfeldt and T. Singh, ACM Mobiwac, in Proc. ACM MSWIM, Chania, Crete, October 2007. Number of citations: 8
- “Multiclass G/M/1 queueing system with self-similar input and non-preemptive priority”, M. Caglar, M. Iftikhar, B. Landfeldt and T. Singh, in Proc. APS Informs, Eindhoven Netherlands, July 2007.
- “Implementation of a Wireless Mesh Network Testbed for Traffic Control”, K. Lan, Z. Wang, R. Berriman, T. Moors, M. Hassan, L. Libman, M. Ott, B. Landfeldt, Z. R. Zaidi A. Seneviratne and D. Quail, IEEE WiMAN 2007, in Proc. ICCCN, Honolulu, USA, August 2007. Number of cictations: 21
- “Dynamically Re-configurable Transport Protocols for Low-End Sensors in Wireless Networks”, K. Premadasa and B. Landfeldt, in Proc. IEEE CNSR, pp. 63-70, Fredericton Canada, May 2007. Number of citations: 1

Book Chapters

- “Nature−Inspired Computing for Autonomic Wireless Sensor Networks”, Wei Li, Javid Taheri, Albert Y Zomaya, Franciszek Seredynski, Bjorn Landfeldt, Chapter 11, pp. 219-254 Large Scale Network-Centric Distributed Systems, A.Zomaya and Sarbazi-Azad eds., Wiley 2013. Number of Citations 1.
- “Deployment of a Wireless Mesh Network for Traffic Control”, Lan, K., Wang, Z., Hassan, M., Moors, T., Berriman, R., Libman, L., Ott, M., Landfeldt, B., Zaidi, Z., & Chou, C. (2012). In M. Matin (Ed.), Developments in Wireless Network Prototyping, Design, and Deployment: Future Generations (pp. 290-310). Information Science Reference. doi: 10.4018/978-1-4666-1797-1.ch014
- Mobility Management in Wireless Mesh Networks”, P. Wu, B. Landfeldt and A. Y. Zomaya, Encyclopedia of Ad Hoc and Ubiquitous Computing, edited by D.P. Agrawal and B. Xie, pp. 587–600, World Scientific Publishing, Singapore. Number of citations: 9
- “Fault Management in Wireless Mesh Networks”, Z. Zaidi, B. Landfeldt and A. Y. Zomaya, Handbook of Mobile, Ad-Hoc and Pervasive Communications, American Scientific Publishers, 2008. umber of citations: 7
- “Access Control in Wireless Local Area Networks”: Fast Authentication Schemes, J. Hassan, B. Landfeldt and A. Y. Zomaya, Handbook of Reserach on Wireless Security, Chapter 44, IGI Global, Yan Zhang; Jun Zheng; Miao Ma eds., ISBN: 978-1-59904-899-4

Patents

- “Creating Distributed Proxy Configurations”, B. Landfeldt et al., US patent no. US 7,200,679 B2, Granted April 3, 2007.
- “Method and System for centrally allocating addresses and port numbers”, B. Landfeldt and A. Seneviratne, US 20060259625, Granted November 16, 2006.
- “Method and system for enabling connections into networks with local address realms”, B. Volz, G. Chambert, M. Körling, B. Landfeldt and Y. Ismailov. US patent no 60/370,812, Granted May 12, 2009. Number of citations: 10
- “Method and apparatus for auto-configuration for optimum multimedia performance”, B. Landfeldt and Jan Höller, US Patent 7,158,788, 2007, Number of citations: 21

Five highest cited works

- “Game-theoretic Approach for Load Balancing in Computational Grids”, R. Subrata, A. Zomaya and B. Landfeldt, IEEE Transactions on Parallel and Distributed Systems 19(1), pp. 66-76, 2007, Number of citations: 87
- “SLM, a Framework for Session Layer Mobility Management”, B. Landfeldt, T. Larsson, Y. Ismailov and A. Seneviratne, in proc. IEEE ICCCN 1999, Boston, MA, USA. Number of citations: 73
- “MARCH: a Distributed Content Adaptation Architecture”, S. Ardon, P. Gunningberg, B. Landfedt, Y. Ismailov and A. Seneviratne, International Journal of Communication Systems 16 (1), pp. 97-115, Number of citations: 65
- “A Cooperative Game Framework for QoS Guided Job Allocation Schemes in Grids”, R. Subrata, A. Y. Zomaya and B. Landfeldt, IEEE Transactions of Computers, vol. 57 no. 10, 2008, pp. 1413-1422. Number of citations: 51
- “Artificial Life Techniques for Load Balancing in Computational Grids”, R. Subrata, A. Zomaya and B. Landfeldt, Journal of Computer and Systems Sciences 73 (8), pp. 1176-1190, 2007, Number of citations: 46

Emma Fitzgerald — Publikationer

Citation databse: Google Scholar

0.1 Fackgranskade originalartiklar (Peer-reviewed original articles)

0.2 Fackgranskade konferensbidrag (Peer-reviewed conference contributions)

2014 * E. Fitzgerald and B. Landfeldt, The Failure of CSMA in Emerging Wireless Network Scenarios, *Wireless Days 2014*
Number of citations: 0

2013 * E. Fitzgerald and B. Landfeldt, Trading Accuracy and Resource Usage in Highly Dynamic Vehicular Networks, *IEEE Intelligent Transportation Systems Conference 2013*
Number of citations: 0

2013 * E. Fitzgerald and B. Landfeldt, On Road Network Utility Based on Risk-Aware Link Choice, *IEEE Intelligent Transportation Systems Conference 2013*
Number of citations: 0

2012 * E. Fitzgerald and B. Landfeldt, A System for Coupled Road Traffic Utility Maximisation and Risk Management Using VANET *IEEE Intelligent Transportation Systems Conference 2012*
Number of citations: 7

0.3 Monografier (Monographs)

2013 * E. Fitzgerald, Achieving Dynamic Road Traffic Management by Distributed Risk Estimation in Vehicular Networks, University of Sydney

0.4 Forskningsöversiktsartiklar (Research review articles)

0.5 Böcker och bokkapitel (Books and book chapters)

0.6 Patent (Patents)

0.7 Egenutvecklade allmänt tillgängliga datorprogram eller databaser (Open access computer programs or databases you have developed)

0.8 Populärvetenskapliga artiklar/presentationer (Popular science articles/presentations)

CV

Name: Björn Landfeldt	**Doctorial degree:** 2000-07-05
Birthdate: 19670825	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Research education

Dissertation title (swe)
Reactive QoS Management from an End-User Perspective

Dissertation title (en)
Reactive QoS Management from an End-User Perspective

Organisation	Unit	Supervisor
University of New South Wales, Australia Not Sweden - Higher Education institutes	Electrical Engineering	Aruna Seneviratne

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20203. Kommunikationssystem		2000-07-05

CV

Name: Emma Fitzgerald	**Doctorial degree:** 2013-08-14
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Dissertation title (swe)		
Dissertation title (en)		
Achieving Dynamic Road Traffic Management by Distributed Risk Estimation in Vehicular Networks		
Organisation	**Unit**	**Supervisor**
University of Sydney, Australia Not Sweden - Higher Education institutes	School of Information Technologies	Björn Landfeldt
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
20203. Kommunikationssystem		2013-08-14

Publications

Name: Björn Landfeldt	**Doctorial degree:** 2000-07-05
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Landfeldt, Björn has not added any publications to the application.

Publications

Name: Emma Fitzgerald	**Doctorial degree:** 2013-08-14
Birthdate: 19860210	**Academic title:** Doktor
Gender: Female	**Employer:** Lunds universitet

Fitzgerald, Emma has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.