Vetenskapsrådet

Application

2015-03-31

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Information about applicant

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Project site: Avdelningen för Kommunikationsteori

Information about application

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

Type of grant: Projektbidrag

Focus: Unga forskare

Subject area:

Project title (english): Effektiv Trådlös Caching för framtida mobila nätverk

Project start: 2016-01-01

Project end: 2019-12-31

Review panel applied for: NT-14

Classification code: 10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)

Keywords: Wireless Caching, Future Mobile Networks, Delay, Throughput

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,300,000	1,300,000	950,000	850,000

Descriptive data

Project info

Project title (Swedish)*

Efficient Wireless Caching for Future Mobile Networks

Project title (English)*

Effektiv Trådlös Caching för framtida mobila nätverk

Abstract (English)*

With emerging new applications (e.g., social networks, mobile video and gaming) and the development of smart terminals, future mobile networks, i.e., the 5th generation mobile networks (5G) and beyond, are essentially characterized as high density, high rates and low delay. For instance, the 5G mobile is expected to be 1000x higher in aggregated rates, 100x higher in density and 10x lower in delay, compared to the 4G mobile, which is already in a very high technical standard. The major of mobile traffic will be multimedia information, e.g., video, which poses very high technical requirements on rates and delay. Thus, new technical breakthroughs on mobile networks are needed in near future. By trading off storage space with rates/delay, wireless caching boosts performance in network throughput and delay. The basic idea of wireless caching is to pre-store the user data in network edges (access nodes or user terminals) such that user requests can be responded locally, rather than from remote nodes. It has been shown that significant (order of) gains in rate/delay can be achieved by wireless caching.

In the project, we seek to study the wireless caching for future mobile networks from information and communication theory aspects. The network model will be high rate, high density and heterogeneous. Our main objectives are to find performance limits and also to propose the performance-improved schemes for wireless caching in future mobile networks. In addition to the delay and throughput of delivering data from caching nodes to user terminals, we will also investigate the robustness of wireless caching networks. We will study the impacts of other important performance measures e.g., power and spectrum (and their tradeoffs) of mobile networks to wireless caching and vice-versa. With decreasing price of storage memory, our results shall help to boost the performance of future mobiles in a cost-efficient way.

Popular scientific description (Swedish)*

Med framväxande nya tillämpningar (t.ex. sociala nätverk, mobil video och spel) och utveckling av smarta terminaler, framtida mobilnät, dvs de 5: e generationens mobilnät (5G) och därefter, i allt väsentligt betecknas som hög, låg fördröjning och stora systemets kapacitet. Till exempel är det 5G mobilen väntas bli 1000x högre i aggregerade priser, 100x högre densitet och 10x lägre fördröjning, jämfört med 4G mobilt, som redan är i en mycket hög teknisk standard. Den stora av mobiltrafiken kommer att vara multimediainformation, t.ex., video, vilket ställer mycket höga tekniska krav på priser och förseningar. Således är nya tekniska genombrott på mobilnät behövs i nära framtid. Genom handel utanför lagringsutrymme med hastighet / fördröjning, ökar trådlös caching prestanda i nätverket genomströmning och förseningar. Den grundläggande idén med trådlös caching är att i förväg lagra användardata i nätverks kanter (accessnoder eller användarterminaler) så att användarnas önskemål kan svarat lokalt, snarare än från avlägsna noder. Det har visat sig att signifikant (ordning) vinster i hastighet / fördröjning kan uppnås genom trådlös caching.

I projektet vi ska studera trådlösa caching för framtida mobilnät från informations och kommunikations teori aspekter. Nätverksmodellen kommer att vara hög hastighet, hög densitet och heterogen. Våra huvudsakliga mål är att hitta prestandagränser och även att föreslå resultat förbättrade system för trådlös caching i framtida mobilnät. Förutom förseningen och genomströmning av att leverera data från caching noder till användarterminaler, kommer vi också att undersöka robustheten trådlösa caching nätverk. Vi kommer att studera effekterna av andra viktiga resultatmått t.ex. makt och spektrum (och deras avvägningar) av mobilnät till trådlösa caching och vice versa. Med minskande priset på lagringsminne, ska våra resultat bidrar till att förbättra prestanda i framtida mobiler på ett kostnadseffektivt sätt.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Deductible time

Deductible time

	Cause	Months
1	Parental leave	7
	Total	7

Career age: 81

Career age is a description of the time from your first doctoral degree until the last day of the call. Your career age change if you have deductible time. Your career age is shown in months. For some calls there are restrictions in the career age.

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*

1. Naturvetenskap > 102. Data- och informationsvetenskap (Datateknik) > 10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)

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

Keyword 1*

Wireless Caching

Keyword 2*

Future Mobile Networks

Keyword 3*

Delay

Keyword 4

Throughput

Keyword 5

Research plan

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*

This is a basic research in the communications and information technology area. There is no any ethical issue for the project.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

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Efficient Wireless Caching for Future Mobile Networks

1. Purpose and aims

This project aims at investigating fundamental theories and practical design principles of applying wireless caching for future mobile systems, which are characterized as high-density, high-rate and low-delay networks. With emerging new applications (e.g., social networks, mobile video and gaming, position-based service) and the development of smart terminals, future mobile networks, i.e., the 5th generation mobile networks (5G) and beyond, are essentially characterized as high rates, low delay and high network density. For instance, the 5G mobile is expected to be about 1000x higher in aggregated rates, 100x higher access-node density and 10x lower in delay ([1], [2], [3]), compared to the 4G mobile, which is already in a very high technical standard. More specifically, from the 4G to the 5G mobile, the inter-access-node distance may be reduced from 200 meters to 10 meters [3]. For the rate aspect, it was estimated that wireless data would increase from under 3 exabytes in 2010 to more than 500 exabytes by 2020. The major of mobile traffic will be multimedia information, e.g., video, which poses very high technical requirements on rates and delay. Thus, new technical breakthroughs on mobile networks are needed in the near future. Motivated by these facts, various candidate technologies have been proposed for future mobile networks ([1], [2], [3]), for instance, millimeter wave (MMW) communications, massive MIMO (Multiple-input multiple-output) antennas and dense network deployment (network densification). Though these techniques addressed parts of the challenges, they also have insufficiencies in certain aspects. For instance, the high directional property of MMW signals makes communications difficult in high mobile scenarios. It is also challenging for massive MIMO implemented at mobile terminals. Though dense deployment (of access nodes) can result high spatial efficiency, the costs (especially the backhauls to connect access nodes) can be quite high. On the other hand, by trading off storage space with rates/delay, wireless caching gives another way of boosting performance [1]. As shown in Figure 1 and 2, the basic idea of wireless caching is to pre-store the user data in network edges (wireless-access-node caching in Figure 1 or user-terminal caching in Figure 2 or some combinations of them) such that user requests can be responded locally, rather than from remote nodes (so-called "Moore's law for bandwidth": larger memory in networks leads to higher per-user bandwidth). It was shown ([4]-[9]) that significant (order of) gains in rate/delay could be achieved by wireless caching. Note that with fast development of IC technologies, the prices of caching memory are quickly decreasing. Thus, the gains by wireless caching will increase (for a given budget).

In the project, we will study the wireless caching for future mobile networks from information and communication theory aspects. The network model will be high rate, high dense and heterogeneous. Our main objectives are to find fundamental limits and also to propose the performance-improved schemes for wireless caching in future mobile networks. In addition to the delay and throughput of delivering data from caching nodes to user terminals, we will also investigate the robustness of wireless caching networks. We will also study the impacts of other important performance measures e.g., power and spectrum (and their tradeoffs) of mobile networks to wireless

caching and vice-versa. With the decreasing price of storage memory, our results seek to boost the performance of future mobile networks in a cost-efficient way.

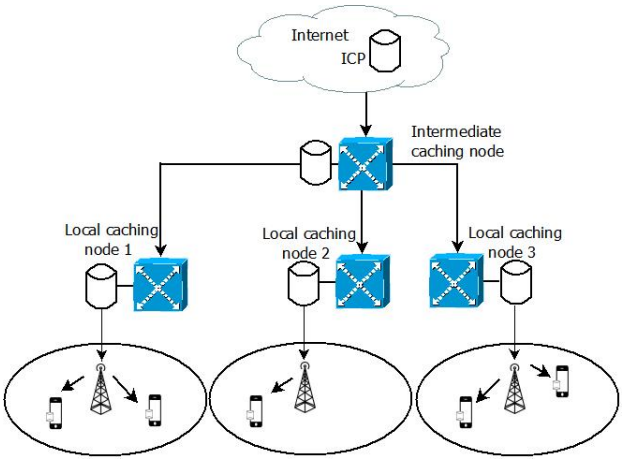

Figure 1. Wireless caching networks with dedicated caching nodes reduce network traffic and response delay.

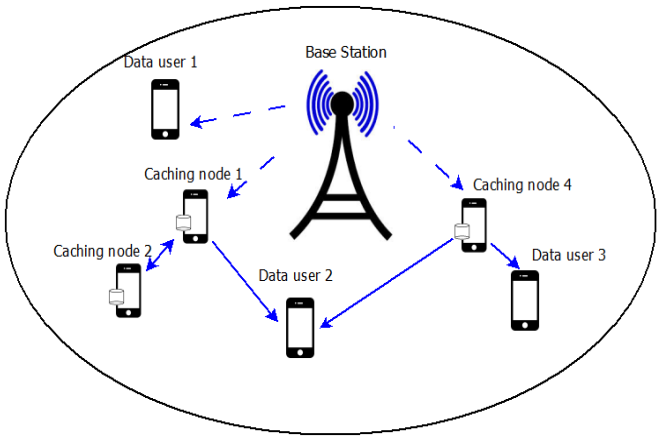

Figure 2. Wireless caching networks with mobile terminal caching nodes and D2D links.

2. Survey of the field

For the potential benefits, the research on wireless caching has recently attracted a lot of attention. Many results focused on information-theoretical performance limits for simplified network models [4], [5]. More recently, results on wireless caching for mobile networks have also been reported [6]-[9]. These endeavors investigated some aspects of wireless caching networks. For instance, reference [4] studied the bounds on the scaling laws of random networks with wireless caching. In [5], authors studied the caching gains in a single wireless broadcasting channel. Reference [6] proposed to use caching in femtocell networks and studied the impact of content popularity distribution to the caching design. In [7], [8], authors proposed to combine D2D (device-to-device) communications with wireless caching and throughput-outage tradeoffs have been analyzed from information-theoretical aspects. To minimize the delay, reference [9] studied the optimal content caching strategies and showed that random caching is near optimality. It is worthy noting that the principle of pre-storing content in nodes close to end-users was proposed for the Internet (e.g., web) for some years [10]-[12]. Yet, results are mainly for wired networks, especially for web caching [10]-[12]. For wireless caching, the network setup, objective, principle and constrains will be significantly different from traditional web caching [4]-[9].

Though pioneer results in [4]-[9] established a good foundation of wireless caching techniques, the research is still in an early stage. There are still many problems on wireless caching to be addressed, especially for applications in mobile networks. For instance, as a wireless access technology, the impacts of wireless caching to many physical layer measures (e.g., spectral efficiency, power) or vice versa have not been investigated yet. Currently, only rate, delay and storage space (also their tradeoffs) were studied, to our best knowledge. Some properties of future mobile networks have not been sufficiently considered yet. Moreover, the major of current results focus on information-theoretical

analysis. More practical design issues have not been addressed yet. Furthermore, as a special type of distributed storage systems, only the content delivery and placement problems have been studied. Robust problems (when caching nodes or data fragments failed or unavailable) have not been well studied yet for wireless caching networks. The existed results on repairing problems of the distributed storage systems ([13], [14]) are mainly for wired networks, e.g., data centers. The system setups and objective functions will be significantly different if we consider wireless caching networks, rather than wired ones. In the mobile networks, caching nodes may often fail due to power outage and node mobility etc. Efficient caching node repairing schemes are necessary for maintaining the reliability and performance of wireless caching networks.

3. Project Description

Based on above observations, in the project, we will study how to combine wireless caching with other potential techniques for future mobile networks, e.g., cooperative relaying, D2D communications, dense network deployment and MMW communications. The performance limits of wireless caching networks in future mobile networks will be analyzed. We will also study how the physical-layer measures (e.g., power and spectrum) impact the performance (e.g., delay) of data delivery (to end users) and how to improve them. Furthermore, we will study the robustness of wireless caching networks, namely, repairing failed (or unavailable) caching nodes for both dedicated caching and user-terminal caching.

More specifically, we will aim at three different but highly related directions (denoted respectively as work packages: WPs). The project staff will consist of PI (Principal Investigator: Dr. Ming Xiao) and two Ph.D students (Student A: new to be recruited; Student B: Majid Gerami for his final 2 years Ph.D study). The specific WPs, staff allocation and timelines are preliminarily planned as follows. Since we already have some results for WP 3, one student and PI are sufficient. WP 1 and WP 2 are new. Thus, a new student (4 years) and PI will be planned for them.

WP 1: Performance limits of wireless caching networks in future mobile networks (PI, Student A; 0-4 years).

Though the pioneer works in [4]-[7] gave the fundamental performance limits of wireless caching networks in different aspects, the performance limits for wireless caching in mobile networks are still insufficient, especially in following aspects. (1), The network models of future mobiles have not been sufficiently considered yet for wireless caching networks. For instance, the high-density and heterogeneous properties of mobile networks have not been sufficiently considered for wireless caching. In [6], [7], the scaling law is studied for wireless networks with an increasing number of user-terminal caching nodes. Yet, for caching in the mobile access nodes (dedicated caching nodes), the scaling laws have not been studied yet, to our best knowledge. Meanwhile, as another key property of future mobile networks ([1]-[3]), the heterogeneous property of future mobile networks has not been considered. As we noted, the access node of future mobile networks will be high dense and heterogeneous. (2), The physical-layer measures of mobile

networks (e.g., power and spectrum efficiency) have not been considered yet. Clearly, for wireless caching, power (thus closely related energy-efficiency) is one of key parameters in practice. For mobile terminals (especially caching terminals), the battery capacity is rather limited. Power determines the lifetime of caching nodes (in some degree) and is one of the key parameters for wireless caching networks. Moreover, with increasing environmental concerns and prices, energy efficiency has become one of key requirements for the 5G mobile and beyond [1]. Thus, similar to caching terminals, the power of access-node caching networks is also important. Hence, it is very important to study the power in wireless caching networks. To find the fundamental performance limits, we plan to use the tools of information theory (especially network information theory) and graph theory, and we will ignore the constraints of complexity (e.g., computation complexity, coding length and delay). More detailed descriptions are as follows.

Firstly, the performance limits (delay, storage, throughputs and their tradeoffs) in high dense networks will be studied. We plan to consider two scenarios of wireless caching networks: All access nodes are caching nodes or only a part of them are caching nodes (those nodes are not caching nodes may still help to delivery content with larger delay). To catch the heterogeneous property of mobile networks, the caching nodes may have different properties, e.g., different response delay or storage capacity. To make the problem tractable, we will consider a layered model (e.g., by a hierarchy network topology). For instance, the BS (base station) may have a larger caching memory but longer delay, compared to femto-stations. We will try to find how throughput per user (or the delay as a dual problem) changes with an increasing number of caching nodes and/or caching memory (in both the user terminals and access nodes). For very dense networks, the scaling law will be studied for layered network models. Meanwhile, it is also worthy to study how content placement impacts the performance. Though reference [9] shows that random caching is almost optimal, the results in [9] are only for homogeneous networks. For layered network models, optimizing caching content placement according to both popularity and the properties of caching nodes may bring extra gains in delay or throughput. For instance, better performance may be expected if we optimize placement among nodes of different layers. Note that a straightforward solution is that the most popular files are cached in the nodes closest to users. However, the situation can be much more complex, if the mobility of user terminals are considered. In such scenario, the terminal may have already moved to another access node (which may not have the downloading file) before download finishes. Another complex situation may be the user terminal can access multiple caching nodes. In general, optimized placement among different layers according to popularity and mobile network properties should be considered to improve performance.

Secondly, we will study the connections between physical-layer measures (transmission power, spectrum) and other parameters (delay, throughput and storage) in wireless caching networks. Preliminarily, we expect that similar to storage space and delay [4], [5], there are also fundamental tradeoffs between transmission power (or similarly spectrum efficiency) and delay (and storage space). For instance, to reduce the delay, we may use larger power or vice-versa. Note that compared to the throughput in [4], [5], power may catch more properties of mobile networks. For

instance, the power level also decides the interference in networks and the battery lifetime of user terminals. The latter is especially critical for user terminal caching scenarios. Clearly, the impacts of power largely depend on network models. We will study both random network models (for mobile terminal caching) and layered models (for access-node caching). Some preliminary results on the tradeoffs between power and data-delivery delay are shown in Figure 3. From the figure, we can clearly see the power gains by caching. Meanwhile, other potential techniques for future mobiles will also be reflected in our network models, e.g., MMW and D2D communications. Preliminary, for MMW communications, a caching node can only respond to one user due to the high directional property of transmission signals. Thus, the global caching gain due to index coding (based on wireless broadcasting) in [4] cannot be expected. Yet, the interference may not be a problem and multiple concurrent content deliveries may be feasible. With D2D communications, obviously an end user can directly transmit content to the nearby users without using access nodes. The important tools will be network information theory and graph theory. For instance, the capacitated tree graph in [4] may be used for our analysis after some modification (since our network models are different).

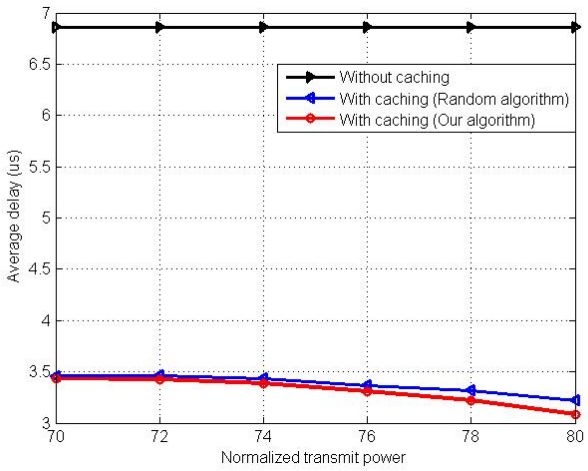

Figure 3. Power gains by caching and power-delay tradeoffs.

WP 2: Efficient communications protocols for wireless caching networks. (Student A, PI; 0-4 years)

With performance limits, we will seek to find efficient communications protocols to approach (even achieve if possible) them with the constraint of complexity. Preliminarily, we plan to use following approaches to boost the performance of wireless caching networks: cooperative communications, network coding and optimal scheduling.

Cooperative communications was originally proposed to increase the reliability and energy efficiency for the user terminals with limited antenna sizes [15], [16]. In [17], the principle of cooperative communications was proposed for the repairing problem of distributed storage systems and showed substantial gain in term of repairing bandwidth. For the close connection, we expect that the principle of cooperative communications can also be used for wireless caching networks in

data placement (from the source to caching nodes) or delivery (from caching nodes to user terminals). For instance, in the data delivery, multiple caching nodes can cooperatively transmit content to a user, especially when channels are unreliable or users are moving. Thus, the gains in throughput (or delay) may be expected. Similarly, network coding will be considered for wireless caching [18] due to intrinsic connection. Currently, major of wireless caching schemes use index coding [4], [5], [19] for data delivery, which is actually a special type of binary network coding. Index coding is optimal for single-hop error-free broadcasting networks. However, if network models are more complexity, index coding may not be optimal. For instance, in the scenarios of heterogeneous or multi-hop networks, more complex network coding (generally in higher field sizes) may be necessary to achieve optimal performance. For a single-hop homogeneous wireless caching networks ([4], [5]), optimized scheduling (determines which caching node transmits to which user terminal) may not be a problem. However, when the network becomes larger or more complex, optimized scheduling may lead to gains in terms of throughput and transmission power etc. In the project, we will study the scheduling algorithms for data delivery in wireless caching networks. We will first formulate the problem of minimizing delay for giving throughput (or maximize throughput for give delay). Then, various scheduling algorithms with limited complexity will be proposed to address the optimization problems. The results will also be compared with the performance limits found in Problem 1.

In [20], we already have some preliminary results on optimal scheduling for the terminal caching networks with D2D communications. In the project, we will also study the scheduling problem for heterogeneous wireless networks with access-node caching. Meanwhile, we will study if optimal grouping (of caching nodes or user terminals) may also bring additional performance gains when network density becomes high.

WP 3: Robustness of wireless caching networks (Student B, PI; 0-3 years. Student B and PI will jointly work on the WP for about 2 years and PI will continue to work on it for another year after Student B graduates):

Since in mobile networks, the caching nodes may not be reliable due to link/power outage or node mobility, the technique of repairing failed (or unavailable) caching nodes is essential for the efficiency of wireless caching networks. We will study the repairing problem for both access-node caching and user-terminal caching. For the former, as in Figure 1, the caching nodes are a part of the mobile infrastructure and may lie in the base-station (BS) or femtocell stations or other wireless access nodes (e.g., relaying nodes). For the latter, as in Figure 2, a node failure may be caused by node mobility or battery empty. In [21], we have preliminarily studied repairing failed caching nodes in broadcasting channels. However, we only solve the problem for special ($2k$, k) caching systems (i.e., $2k$ coded fragments are used to store k data fragments. Each node stores one fragment and any k fragments can rebuild the resource) and each node loses exactly one data fragment.

In the project, we will extend the result in [21] to more general setups. Firstly, we will study repair in wireless caching networks with more general system topologies (heterogeneous and high

dense topology for future mobile networks) and arbitrary data loss. Similar to [13], [14], we will find the tradeoff between storage space and bandwidth (may be also replaced by spectrum and power in wireless setups). Note that the tradeoff in Problem 1 is for data delivery or placement. In Problem 3, the tradeoff is for node repairing. The problems are different since in repairing, the new node (as the receiver) does not need to rebuild the source. Different from [13], [14], the channels in wireless caching are broadcasting and prone to transmission errors. Meanwhile, we will try to find optimal network coding and transmission schemes to achieve the tradeoffs. Secondly, the dynamics of network models will be considered. Due to node mobility or channel/node outage in mobile networks, the topology is dynamic. Thus, it is valuable to study repairing problems for dynamic caching networks. In such scenario, the successful repairing will not be deterministic (for the given number of transmission). New measures should be proposed. For instance, we may consider the probability of successful repairing (PSR). Thirdly, physical-layer measures (power, spectrum efficiency) will be studied for repairing since in mobile networks, they are also essential. While in Problem 1 we will investigate the power for data delivery (from caching nodes to end users) or placement, we will in Problem 3 mainly study the power for repairing failed caching nodes.

4. Significance

In pioneer work [4]-[9], wireless caching has already shown significant gains (order of) in terms of throughput and delay. Yet, the research of applying wireless caching to future mobile networks is still in a quite early stage. Many properties of future mobile networks have not been sufficiently considered yet for wireless caching networks, e.g., high dense, heterogeneous, high rate and low-delay etc. This hinders the application of wireless caching to future mobile networks, which might be one of the most important applications for wireless caching. The planning work in the project seeks to address these problems (in some degree).

We expect our results will produce solid impacts in both academy and industry. Our research results are mainly in the form of scientific publications in top journals and conferences (if feasible, we will patent some results as well). Through journal publications and conference presentation, and collaboration networks, our research will spread in the scientific community. Since we seek to be fundamental and involving multiple areas (e.g., information theory, optimization, coding, graph theory etc), the scientific impacts of our results are expected to be solid. Meanwhile, it is expected that 5G mobiles will start to be deployed in near future, i.e., around year 2020. Our results may also get good attention in industries too. Also, through existed collaboration, the research results may be expanded to industry partners e.g., Ericsson.

5. Preliminary results

As preliminary results, we considered the repairing problem in wireless distributed storage systems [21]-[23]. More specifically, in [22], we extended the objective function of bandwidth in [13], [14] to more general costs and consider the multi-hop topology, which is one of essential properties of

wireless networks. Reference [23] considers the channel error (packet erasure), which is another important property of wireless networks. In [21], we studied the repair problem in some special caching networks with broadcasting channels. We considered the scenario of partial repair, where only parts of stored data of a node(s) are lost and repaired. In [20], we studied the optimal scheduling and power allocation to minimize the delay for the data delivery of caching networks.

6. Independent line of research

The project PI already has certain research achievements in network coding, channel coding, wireless communications and information theory. However, the techniques of mobile networks have developed very quickly. This project will make the involved researchers (PI and students) updated to the recent developments of wireless communications. Moreover, the project will further train the involved researchers in knowledge areas in which they may still have insufficiency (e.g., optimization, graph theory) and project management skills.

The host department will be KTH, the communication theory, which presently has 2 full professors, 5 Associate Professors (including PI), about 20 Ph.D students and Postdocs. The lab is also a part of the ACCESS research center funded by VR Linnaeus grant. The host lab is a large group. However, Dr. Ming Xiao is the only senior researcher *independently* working on this topic (wireless caching). The senior researchers at the host group have different expertise. The expertise of Dr. Xiao is network coding, cooperative communications and coding for storage. He has also done substantial research in wireless communications, information theory and optimization. Dr. Xiao will independently lead the project as the principal researcher. Certainly, in some aspects, collaboration with other senior researchers of the same department is expected. For instance, Prof. Skoglund is an expert in wireless communications and information theory. Collaboration in these directions is feasible and very helpful. Yet, the main research work will be done independently by PI and involved students.

The project leader, Dr. Ming Xiao got his Ph.D degree for more than 6 years. The project is fully independent to his research during Ph.D study.

7. Form of employment

The project PI, Ming Xiao, is currently an Associate Professor (UniversitetsLektor in Swedish) at KTH, communication theory department (80% research and 20% teaching or other duty). He holds a permanent position at KTH. The involved students will be employed as Ph.D students, according to regulations at KTH.

8. International and national collaboration

Based on existed collaboration, we shall collaborate with international leading scientists for the project, specifically, with Prof. Muriel Medard at MIT (joint publication, mutual visits), USA, and

with Prof. Vincent H. Poor at Princeton University (joint publication, visits), and with Prof. Raymond Yeung (mutual visits) at the Chinese University of Hong Kong, and with Giuseppe Caire at TU-Berlin (on-going joint EU project application), and with Prof. Shlomo Shamai at Technion, Isreal (joint publication), and collaboration with Prof. Jinhong Yuan, University of New South Wales (visits and joint publication), Australia, and Prof. Branka Vucetic, University of Sydney (visits and joint publications).

Within Sweden, in the academic aspect, collaborations within VR-funded ACCESS Linnaeus center (e.g., Associate Prof. Carlo Fischione, György Dan, Viktoria Fodor with joint publications or projects) and within host communications lab will be expected. In the industrial side, future collaboration with Ericsson is expected for this project. The host group (communication theory group in KTH) has already established close collaborations with Ericsson Research in Kista. Dr. Ming Xiao has also actively cooperated with different departments of Ericsson research through joint projects, for instance, "WINNER+" project with Dr. Afif Osserian (also joint publications). He also leaded an EIT ICT Lab project, which has the cloud department of Ericsson research as the partner (with Mr. Per Pelle Karlsson, Ayodele Damola, Dr. Henrik Abramowicz). There are joint meetings and workshops for discussing projects and new research direction. Thus, a further collaboration with Ericsson within this project is feasible. This also gives opportunities to bring theoretical research to the practical applications.

9. Other grant

Currently PI has no other grants with a similar idea (topic), and he has no any running project from VR either. But PI also applied VR international career grant in March 2015 (result pending). The project title is "A Study of Distributed Storage Systems for Big Data Applications" (Register Number: 2015-00627), which has a completely different idea relative to this application (aiming at wired networks and data analysis). The grant application will follow the regulations of VR.

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[9] N. Golrezaei, P. Mansourifard, A. Molisch and A. Dimakis, "Base-station Assisted D2D Communications for High-Throughput Wireless Video Networks," IEEE Trans. on Commun., July, 2014.
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[14] Y. Wu, "Existence and construction of capacity-achieving network codes for distributed storage," IEEE Journal on Selected Areas in Commun., vol. 28, no. 2, pp. 277-288, Feb. 2010.
[15]A. Sendonaris, E. Erkip, and B. Aazhang (2003). "User cooperation diversity. Part I. System description". *IEEE Transactions on Communications* **51** (11): 1927–1938, Nov. 2013.
[16] M. Xiao and M. Skoglund, "Multiple-user cooperative communications based on linear network coding", *IEEE Transactions on Communications*, vol. 58, no. 11, December 2010.
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[18] R. Ahlswede, N. Cai, S.-Y. Li, and R. Yeung, "Network information flow," *IEEE* Transactions on Information Theory, vol. 46, no. 4, pp. 1204–1216, 2000.
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[21] M. Gerami, M. Xiao and M. Skoglund, "Partial repair for wireless caching networks with broadcast channels," *IEEE* Wireless Communications Letters, Dec. 2014.
[22] M. Gerami, M. Xiao, M. Skoglund and K. Shum, "Optimized-cost repair in multi-hop distributed storage systems with network coding," submitted to IEEE/ACM Transactions on Networking, 2013 (conference version published in IEEE ISIT 2011).
[23] M. Gerami and M. Xiao, "Repair for Distributed Storage Systems with Erasure Channels," in Proc. IEEE International Conferences on Communications (ICC), June 2013.

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

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	Ming Xiao	60
2	Other personnel without doctoral degree	Majid Gerami (current Ph.D student)	80
3	Other personnel without doctoral degree	New Student	80

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Ming Xiao	30	300,000	300,000	300,000	300,000	1,200,000
2	Other personnel without doctoral degree	Majid Gerami (current Ph.D student)	80	500,000	500,000	100,000	0	1,100,000
3	Other personnel without doctoral degree	New Student to be recurited	80	450,000	450,000	500,000	500,000	1,900,000
	Total			1,250,000	1,250,000	900,000	800,000	4,200,000

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	Traveling to conference or visiting	50,000	50,000	50,000	50,000	200,000
	Total	50,000	50,000	50,000	50,000	200,000

Running Costs

Running Cost	Description	2016	2017	2018	2019

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	1,250,000	1,250,000	900,000	800,000	4,200,000		4,200,000
Running costs					0		0
Depreciation costs					0		0
Premises	50,000	50,000	50,000	50,000	200,000		200,000
Subtotal	1,300,000	1,300,000	950,000	850,000	4,400,000	0	4,400,000
Indirect costs					0		0
Total project cost	1,300,000	1,300,000	950,000	850,000	4,400,000	0	4,400,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

The applicant, Ming Xiao, will spend 60% time in the project. But he will only claim 30% salary from the project budget. Other part of salary will be paid from KTH faculty funding or teaching (now Ming Xiao is an Associate Professor at KTH with permanent position).

The Ph.D student Majid Gerami will graduate in about 2 years. He will get support for 80% salary from the project.

Another new Ph.D student will be recurited for the project. He will be supported for 80% salary from 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

Curriculum Vitae of Ming Xiao

1. Higher education degrees

- Master in Engineering, 2002, Computer Software and Networks, University of electronic science and technology of China (UESTC), Chengdu, China.
- Bachelor in Engineering, 1997, Image Transmission and Processing, University of Electronic Science and technology of China (UESTC), Chengdu, China.

2. Doctoral degree:

- Doctor degree awarded in November 23th, 2007, Chalmers University of Technology, Sweden. The subject area: "Telecommunication Theory".
- Ph.D thesis entitle "Efficient Coding Techniques for Networks & Channels with Transmission Errors"
- Thesis Supervisor: Professor Tor Aulin.

3. Postdoctoral Positions

- November 2007--December 2008, Post-doctor, communication theory group, Linnaeus ACCESS center, Royal institute of technology (KTH), Sweden.

4. Docent Qualification

- Docent in Communication Theory, Awarded in August 2012, KTH, Sweden.

5. Present Position

- June 2013 --- Now, Associate Professor ("Lektor" in Swedish, Permanent Position) Royal institute of technology (KTH). 80% Research.

6. Previous position and periods of appointment

- January 2009 – May 2013, Assistant Professor, KTH, Sweden, Full time.
- August 1997 – August 1999, ChinaTelecom, SiChuan Branch, network engineer.

7. Interruptions in research

Parental leave: 7 months (3 months in 2011 and 4 months in 2013).

8. Supervision (as main supervision)

- Dengsheng Lin, PostDoc, at KTH, (2011 – 2012).
- Majid Gerami, Ph.D student, KTH, (2012 – 2017).
- Gang Yang, Ph.D student, KTH, (2013 – 2018).

9. Other information

9.1. PROFESSIONAL ACTIVITIES

- Editor: IEEE Transactions on Communications (since August 2012, handled 49 papers);
- Senior Editor: IEEE Communications Letters (Feb. 2015 --- Now).

- Editor: IEEE Wireless Commu. Letters (since Sept. 2012, handled 36 papers).
- Editor: IEEE Communications Letters (August 2012---Feb. 2015, handled 117 papers);
- Co-supervisor for 6 Ph.D students (Jinfeng Du, Ph.D in November 2012; Iqbal Hussain, Ph.D Dec. 2014; Lu Lu Licentiate in September 2011; Zhao Wang; Nan Li, Rong Du). Host visiting students (Nan Qi, 2013-3015; Lin Zhang, 2014-2016; Yang Liu, 2015).
- Granted research projects (total amount > 10Million SEK) as PI (principal investigator), significant ones:
  (1) PI "Smart content delivery and storage in mobile networks with network coding", Funded by European institute of innovation & technology (EIT), 2013 – 2015;
  (2) PI: "Efficient Rateless Codes for Wireless Networks", Funded by **VR** (Swedish research council), 2009-2012.
  (3) PI: "Wireless Cooperative Communications with Network Coding", **VR**, 2008.
  (4) Co-PI, "Quality-of-Experience Improvement for Mobile Multimedia across Heterogeneous Wireless Networks", EU Marie-Curie, 2014-2017.
- TPC Co-chair, IEEE Communication Systems and Networks Symposium, ICCCAS (International Conference on Communications, Circuits and Systems), 2013;
- TPC Co-chair, IEEE Vehicular Technologies Conference (VTC 2014) Fall, Track "Cooperative Communications, Distributed MIMO and Relaying"，2014;
- Technical Program Committee (TPC) Member: IEEE Globecom 2007, 2013, 2014 ICC 2012-2015, WCNC 2010-2015, VTC 2011, 2014, Pimrc 2011, 2012.
- 2 invited talks and 1 keynote speech.
- IEEE Senior Member.
- External Ph.D examiner: City University of HongKong, University of Sydney 2014 and University of Porto, 2012.
- Technical Reviewers, IEEE Transactions on Communications (Reviewed 25 papers), IEEE Transactions on Wireless Communications (Reviewed 26 papers), IEEE Transactions on Information Theory (Reviewed 4 papers), IEEE Communications Letters (Reviewed 20 papers), IEEE Trans. on Vehicular Technologies (Reviewed 10 papers).

9.2. Academic Visits

- October 2006 -- March 2007: Massachusetts Institute of Technology (MIT), Cambridge, USA, visiting research associate, Lab. for Info. & Decision Systems (LIDS). Hosted by Professor Muriel Medard.
- August 2010 – October 2010, Institute of network coding, the Chinese University of Hong Kong, Visiting Professor, Hosted by Professor Raymond Yeung.
- July, 2009, University of New South Wales, Australia, Visiting Professor.

9.3. HONORS and AWARDS

- "Best Paper Award", IEEE ICCCN (International Conference on Computer Communication Networks), 2011. Sole Awarded Paper of the conference. Homepage: http://www.icccn.org/icccn11/award.html
- "Best Paper Award", International Conference of Wireless Communications on Signal Processing (IC-WCSP), 2010.
- "Chinese Government Award for Outstanding Self-Financed Students Abroad" (国家优秀自费留学生奖), March, 2007.
- "Hans Werthen Grant" by *Royal Swedish Academy of Engineering Science* (IVA), 2006.
- "IEEE Student Travel Grant" as the main recipient, IEEE ISIT 2004, IEEE ISIT 2006, Globecom 2005. Another 5 as co-recipient (co-author)
- "Ericsson's Research Foundation", Ericsson Research, 2010.

Publication list

List of Publications

Total Citation (by Google Scholar on March 30, 2015): 972. H-index: 18.

Homepage: https://scholar.google.se/citations?user=_6__AdwAAAAJ&hl=en&oi=sra

5 most significant/relevant papers are marked with *.

1. Peer-reviewed original articles (*citations are from google scholar)*

[J30] K. Song, B. Ji, Y. Huang, M. Xiao and L. Yang, "Performance Analysis of Antenna Selection in Two-way Relay Networks," *IEEE Transactions on Signal Processing,* Accepted and Published online, in Feb., 2015. DOI 10.1109/TSP.2015.2414904, (cited by 0).

*[J29] M. Gerami, M. Xiao and M. Skoglund, "Partial Repair for Wireless Caching Networks with Broadcasting Channels," *IEEE Wireless Communications Letters,* Accepted and Published online, December, 2014. DOI 10.1109/LWC.2014.2386879 (cited by 0).

[J28] Z. Wang, M. Xiao, C. Wang and M. Skoglund, "Degree of Freedom of two-hop MISO Broadcast Networks with Mixed CSIT," *IEEE Transactions on Wireless Communications*. Vol. 13, No. 12, pp. 6982-6995, December, 2014. (cited by 0).

[J27] I. Hussian, M. Xiao, L. Rasmussen, "Buffer-based Distributed LT Codes," IEEE Transactions on Communications, Vol. 62, no. 11, pp. 3725-3739, November 2014. (cited by 1).

[J26] I. Hussian, M. Xiao, L. Rasmussen, "Rateless Codes for Multi-way Relay Channels," IEEE Communications Letters, Vol. 3, no. 5, pp. 457-460, October 2014. (cited by 1)

[J25] Z. Wang, M. Xiao and M. Skoglund, "Secrecy Degree of Freedom of the 2x2x2 Interference Channel with Delayed CSIT", *IEEE Wireless Communications Letters,* Vol. 3, pp. 341-344, August, 2014. (cited by 1).

[J24] J. Li, Z. Lin, B. Vucetic, J. Xu, M. Xiao, and W. Chen, "Threshold-based One-bit Forwarding for a Network Coded Multi-source Single-relay System," *IEEE Transactions on Communications vol. 62, No. 5, pp. 1604-1620. May 2014.* (cited by 0)

[J23] Z. Fei, C. Cao, M. Xiao, I. Hussain and J. Kuang, "Improved LT Codes in Low Overhead Regions for Binary Erasure Channels," *Transactions on Emerging Telecommunications Technologies (former European Transactions on Telecommunications), Published online Feb. 2014*. (cited by 2*)*

[J22] A. Yang, Z. Fei, C. Xing, M. Xiao, J. Yuan and J. Kuang, " Design of Binary Network Codes for Multi-user Multi-way Relay Networks," *IEEE Transactions on Vehicular Technologies, pp. 3786-3799, October 2013.* (cited by 3)

[J21] Z. Wang, M. Xiao, C. Wang and M. Skoglund, "Degree of Freedom of MIMO-Broadcast Broadcast Networks with Delayed CSIT", *IEEE Wireless Communications Letters, pp. 207-210, April 2013*. (cited by 5)

[J20] I. Hussian, M. Xiao, L. Rasmussen, "Design of LT codes With Equal and Unequal Erasure Protection over Binary Erasure Channels", IEEE Communications Letters, pp. 261-264, February 2013. (cited by 9)

[J19] C. Cao, Z. Fei, M. Xiao, G. Huang, C. Xing and J. Kuang, "An Extended Packetization-aware Mapping Algorithm for Scalable Video Coding in Finite-length Fountain Codes", Science China (Information Sciences), Springer, April 2013. (cited by 3)

[J18] D. Lin, M. Xiao, and S. Li, “Packet-combining Based on Cross-packet Coding”, Science China (Information Sciences), Springer, February 2013. (cited by 0)

*[J17] M. Xiao, J. Kliewer and M. Skoglund, “Design of network codes for multiple-user multiple relay wireless networks,” *IEEE Transactions on Communications, Vol. 60, Issue 12, pp. 3755-3766, December, 2012*. (cited by 78)

[J16] J. Du, M. Xiao, M. Skoglund and M. Medard, "Wireless multicast relay networks with limited-rate source-conferencing," *IEEE Journal of Selected Areas in Communications* August 2013. (cited by 10).

[J15] J. Li, J. Yuan, R. Malaney, M. Xiao, and Wen Chen, “Full-diversity Binary-Field Network Codes for a Multiple-Source Multiple-Relay Network,” *IEEE Transactions on Vehicular Technologies, pp. 1346-1360, March 2012*. (cited by 25)

[J14] L. Lu, M. Xiao, L. Rasmussen, “Design and Analysis of Relay-aided Broadcast using Binary Network Codes”, Journal of Communications (JCM), Special Issue on Advances in Communications and Networking, November 2011, (Invited). (cited by 10)

[J13] J. Du, E. G. Larsson, M. Xiao and M. Skoglund, "Optimal symbol-by-symbol Costa precoding for a relay-aided downlink channel," *IEEE Transactions on Communications*. vol. 59, pp. 2274—2284, August 2011. (cited by 5)

*[J12] M. Xiao and M. Skoglund, “Multiple-user cooperative communications based on linear network coding”, *IEEE Transactions on Communications*, vol. 58, no. 12, Dec. 2010. (cited by 115)

[J11] M. Xiao, M. Medard, T. Aulin, “Cross-layer Design of Rateless Random Network Codes for Delay Optimization”, IEEE Transactions on Communications, pp. 3311-3322, vol. 59, no. 12. Dec. 2011. (cited by 28)

[J10] D. Lin, M. Xiao, Y. Xiao and S. Li, “Efficient Packet Combining Based on Packet-level Coding”, IET Electronics Letters, April, 2011. (cited by 5)

[J9] C. Wang, M. Xiao, and M. Skoglund, “Diversity-multiplexing tradeoff analysis of coded multi-user relay networks,” IEEE Transactions on Communications, vol. 59, pp. 1995-2005, July, 2011. (cited by 20)

[J8] J. Du, M. Xiao, and M. Skoglund, “Cooperative network coding strategies for wireless relay networks with backhaul,” IEEE Transactions on Communications , vol. 59, pp. 2502—2514, Sep. 2011. (cited by 21)

[J7] J. Li, J. Yuan, R. Malaney, M. Azmi, and M. Xiao, “Network Coding Based LDPC Code Design for a Multi-source Relaying System,” IEEE Transactions on Wireless Communications, Vol. 10, pp. 1538-1551, May 2011. (cited by 34)

[J6] M. Xiao and T. Aulin, “Optimal Decoding and Performance Analysis of a Noisy Channel Network with Network Coding,” *IEEE Transactions on Communications*, May 2009. (cited by 47)

[J5] M. Xiao and T. Aulin, “On the Bit Error Probability of Noisy Channel Networks with Intermediate Node Encoding,” *IEEE Transactions on Information Theory*, November, 2008, pp. 5188-5198. (cited by 11)

[J4] M. Xiao and T. Aulin, “On Analysis and Design of Low Density Generator Matrix Codes for Continuous Phase Modulation,” *IEEE Transactions on Wireless Communications*, September, 2007, pp. 3440-3449. (cited by 9)

[J3] M. Xiao and T. Aulin, “Serially Concatenated Continuous Phase Modulation with Ring Convolution Codes,” *IEEE Transactions on Communications*, August 2006, pp. 1387-1396. (cited by 49)

[J2] M. Xiao and T. Aulin, “Serially Concatenated Continuous Phase Modulation with Symbol Interleavers: Performances, Properties and Design Principles,” *European Transactions on Telecommunications*, July/August 2006. (cited by 15)

[J1] M. Xiao and T. Aulin, “Irregular Repeat Continuous Phase Modulation,” *IEEE Communication Letters*, August, 2005. (cited by 22)

2. Peer-Reviewed Conference Contributions (Citations are from google scholar)

[C63] Z. Wang, M. Xiao, M. Skoglund and V. H. Poor, "Secrecy Degrees of Freedom of Wireless X Networks Using Artificial Noise Alignment" in *Proc. IEEE ISIT 2015 (To Appear)*. (cited by 0)

[C62] Z. Wang, M. Xiao, M. Skoglund and V. H. Poor, "Secrecy Degrees of Freedom of the Two-user MISO Broadcast Channel with Mixed CSIT" in *Proc. IEEE ITW 2015 (To Appear)*. (cited by 0)

[C61] R. Du, L. Gkatzikis, C. Fischione and M. Xiao, "Energy Efficient Monitoring of Water Distribution Networks via Compressive Sensing," *IEEE ICC 2015 (To Appear)*. (cited by 0).

[C60] A. Phutathum, M. Gerami, M. Xiao and D. Lin, "A Study of Distributed Storage Systems with Network Coding in Wireless Networks," *IEEE ICCS, November 2014*. (cited by 0)

[C59] K. Song, B. Ji, Y. Huang, M. Xiao and L. Yang, "Performance Analysis of Antenna Selection in Two-way Decode-Forward Relay Channels," IEEE VTC Fall, September, 2014. (cited by 0)

[C58] N. Li, M. Xiao, and L. Rasmussen, "Cooperative-based Network Coding in Cognitive Radio Networks," IEEE VTC Fall, September, 2014. (cited by 0).

[C57] J. Du, M. Medard, M. Xiao and M. Skoglund, "Scalable upper bounding models for wireless networks," *IEEE International Symposium on Information Theory, 2014*. (cited by 0)

[C56] I. Hussain, I. Land, T. Chan, M. Xiao, and L. Rasmussen, "A New Design Framework for LT Codes over Noisy Channels," IEEE International Symposium on Information Theory (ISIT), 2014. (cited by 1)

[C55] J. Li, Z. Lin, B. Vecutic, M. Xiao and W. Chen, “One-bit Soft Forwarding for Network Coded Uplink Channels with Multiple Sources” in Proc. IEEE International Conferences on Communications (ICC), 2014. (cited by 0)

[C54] M. Gerami and M. Xiao, “Exact Optimized-cost Repair in Multi-hop Distributed Storage Networks,” in Proc. IEEE International Conferences on Communications (ICC), 2014. (cited by 1).

[C53] C.-L. Wu, M. Xiao, S.-L. Shieh, P.-N. Chen and M. Skoglund, "A two-phase maximum-likelihood sequence estimation for receivers with partial CSI," in *Proc. ICICS 2013*. (cited by 0).

[C52] J. Manssour, J. Du and M. Xiao, "Network-coding-aware link adaption for wireless broadcast transmission," IEEE APWCS 2013. (cited by 0).

[C51] Z. Wang, M. Xiao, C. Wang and M. Skoglund, "On the degrees of freedom of two-hop MISO broadcast networks with mixed CSIT," in Proc. IEEE Globecom 2013. (cited by 1).

[C50] C.-L. Wu, M. Xiao and M. Skoglund, "Joint data and channel estimation using semi-blind MLSE algorithms," in Proc. IEEE SPAWC 2013. (cited by 0).

[C49] J. Du, M. Medard, M. Xiao and M. Skoglund, "Lower bounding models for wireless networks," *IEEE International Symposium on Information Theory, 2013*. (cited by 0).

[C48] I. Hussain, M. Xiao, and L. Rasmussen, "Regularized Variable-node LT Codes with Improved Erasure Floor Performance," *IEEE Information Theory and Applications (ITA) Workshop, January 2013 (Invited)*. (cited by 4).

[C47] M. Gerami, M. Xiao, C. Fischione and M. Skoglund, “Decentralized Minimum-cost Repair for Distributed Storage Systems,” in Proc. IEEE International Conferences on Communications (ICC), June 2013. (cited by 4).

*[C46] M. Gerami and M. Xiao, “Repair for Distributed Storage Systems with Erasure Channels,” in Proc. IEEE International Conferences on Communications (ICC) , June 2013. (cited by 3).

[C45] Z. Wang, C. Wang, M. Xiao and M. Skoglund, "Two-hop MISO Broadcast Network with Quantized Delayed CSIT" in Proc. *IEEE Wireless Communications & Networking Conference (WCNC) 2013, ShangHai, April 2013*. (cited by 1).

[C44] I. Hussain, M. Xiao, and L. Rasmussen, "Reduced-Complexity Decoding of LT Codes over Noisy Channels," *IEEE Wireless Communications & Networking Conference (WCNC) 2013, ShangHai, China April 2013*. (cited by 2).

[C43] I. Hussain, M. Xiao, L. Rasmussen, “Unequal Error protection of LT Codes over Noisy Channels," Proceeding of IEEE Swedish Communication Technologies Workshop November 2012. (cited by 7).

[C42] M. Girnyk, M. Xiao, and L. Rasmussen, "Power Allocation for Multi-Hop Decode-and-Forward Cognitive Radio Networks with Line Topology," IEEE Swedish Communication Technologies Workshop, 2012. (cited by 1).

[C41] Z. Wang, C. Wang, M. Xiao and M. Skoglund, "On the achievable degrees of freedom of partially cooperative X networks with delayed CSIT," in Proc. IEEE Globecom 2012. December 2012. (cited by 0).

[C40] J. Du, M. Xiao, M. Skoglund and S. (Shitz) Shamai, "Short-message noisy network coding with partial source cooperation," in Proc. IEEE ITW September 2012. (cited by 7).

[C39] I. Hussain, M. Xiao, L. Rasmussen, “Design of Spatially Coupled LT Codes,” Proceeding of IEEE PIMRC 2012 (cited by 1).

[C38] M. Girnyk, M. Xiao, L. Rasmussen, “Cooperative Communication in Multi-source Line Networks,” Proceeding of IEEE WCNC, 2012, (cited by 4).

[C37] C. Wang, M. Xiao, L. Rasmussen, “Performance Analysis of Coded Secondary Relaying in Overlay Cognitive Radio Networks,” Proceeding of IEEE WCNC. 2012. (cited by 3).

[C36] I. Hussain, M. Xiao, L. Rasmussen, “Error floor analysis of LT codes over the additive white Gaussian noise channel,” Proceeding of IEEE Globecom December 2011. (cited by 24).

[C35] M. Xiao and M. Skoglund, “On network coding with finite channel state information,” IEEE International Symposium on Wireless Communication Systems, 2011. **(Invited)**. (cited by 1)

[C34] L. Lu, M. Xiao and L. Rasmussen, “Efficient Scheduling for Relay-Aided Broadcasting with Random Network Codes” in Proc. IEEE PIMRC August 2011. (cited by 5).

[C33] M. Girnyk, M. Xiao and L. Rasmussen, “Optimal Power Allocation in Multi-hop Cognitive Radio Networks,” in Proc. IEEE PIMRC September 2011. (cited by 7)

*[C32] M. Gerami, M. Xiao and M. Skoglund, “Optimal-Cost Repair in Multi-hop Distributed Storage System,” in Proc. IEEE International Symposium on Information Theory (ISIT), August, 2011. (cited by 17)

[C31] L. Lu, M. Xiao, L. Rasmussen, “Relay-aided Broadcasting with Instantaneously Decodable Binary Network Codes”, in Proc. IEEE International Conference on Computer Communication Networks (ICCCN), August, 2011 (**Best Paper Award**). (cited by 5)

[C30] J. Li, J. Yuan, R. Malaney, and M. Xiao, “Binary Field Network Coding Design for Multiple-Source Multiple-Relay Networks,” in Proc. IEEE, International Conference on Communications (ICC), June 2011. (cited by 9)

[C29] C. Wang, M. Xiao and M. Skoglund, “Access Protocols for Coded Multi-Source Multi-Relay Networks,” in Proc. IEEE, International Conference on Communications (ICC), June 2011. (cited by 1)

[C28] J. Du, M. Xiao and M. Skoglund, “Backhaul-Supported Wireless Multicast Relay Networks with Cross-Links,” in Proc. IEEE, International Conference on Communications (ICC), June 2011. (cited by 3)

[C27] A. Osseiran, M. Xiao, S. Slimane and M. Skoglund, “Advances in Wireless Network for IMT-Advanced & Beyond,” in Proc. Wireless ViTAE, March 2011 (**Invited**). (cited by 0)

[C26] A. Osseiran, K. Doppler, C. Ribeiro, M. Xiao, M. Skoglund, J. Manssour, “Advances in Device-to-Device Communications and Network Coding for IMT-Advanced”, Proceeding of ICT-Mobile Summit 2009. (cited by 52)

[C25] I. Hussain, M. Xiao, L. Rasmussen, “Serially Concatenated LT Code with DQPSK Modulation”, Proceeding of IEEE WCNC March 2011. (cited by 2)

[C24] J. Du, M. Xiao and M. Skoglund, "Capacity bounds for relay-aided wireless multiple multicast with backhaul," in *Proc. WCSP October 2010*. (**Best Paper Award)**. (cited by 2)

[C23] C. Wang, M. Xiao and M. Skoglund, "Diversity-multiplexing tradeoff analysis of multi-source multi-relay coded networks," in *Proc. ISITA 2010*. October 2010. (cited by 2)

[C22] L. Lu, M. Xiao, L. Rasmussen, “Efficient Scheduling for Relay-Aided Broadcasting with Network Coding”, in Proc., ISITA, October 2010. (cited by 5)

[C21] I. Hussain, M. Xiao, L. Rasmussen, “LT Coded MSK over AWGN Channels”, Proceeding of ISTC (cited by International Symposium on Turbo Codes). 2010. (cited by 5)

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3. Review Articles or Magazine

N/A

4. Books and Book Chapters

[B1] Afif Osserian, Ming Xiao, “Network coding in Wireless Communications,” in Book “Mobile and Wireless Communications for IMT-A and Beyond”, John Wiley & Sons, Publisher, ISBN: 9781119993216, August 2011. (cited by 34)

5. Patents (Granted)

1. Dengsheng Lin, Ming Xiao and Shaoqian Li, “A Packet-level Error Correction Method Based on Rateless Mode,” (China) Patent No.: CN 200910265069, Application 2009; Granted 2013.
2. Dengsheng Lin, Ming Xiao and Shaoqian Li, “A Packet-level Error Correction Method Based on Forward Mode,” (China) Patent No.: CN 200910265068, Application 2009; Granted 2013.
3. Dengsheng Lin, Ming Xiao and Shaoqian Li, “A Packet-level Error Correction Method Based on Feedback Mode,” (China) Patent No.: CN 200910265070, Application 2009 Granted 2013.

4. Dengsheng Lin, Qing Zhang, Ming Xiao and Shaoqian Li, “A new decoder for systematic binary deterministic rateless codes,” (China) Patent No.: CN 201110136551, App. 2011 Granted 2013.
5. Dengsheng Lin, Qing Zhang, Ming Xiao and Shaoqian Li, “A new decoder for LT codes,” (China) Patent No.: CN 201110136345, Application 2011 Granted 2013.

CV

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Dissertation title (swe)

Dissertation title (en)

Efficient Coding Techniques for Network & Channels with Transmission Errors

Organisation	Unit	Supervisor
Chalmers tekniska högskola, Sweden Sweden - Higher education Institutes	3723 - Network & Systems	Tor Aulin

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)	1651-4971	2007-11-16

Publications

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Xiao, Ming 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.