Application

2015-03-31

2015-05433	Dahman, Ghassan	NT-14

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Information about application

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Descriptive data

Project info

Project title (Swedish)*

Nedlänkstransmission i storskaliga FDD MIMO-system baserat på riktningsegenskaper i upplänken

Project title (English)*

Downlink Transmission in FDD Massive MIMO Systems based on Uplink Directional Properties

Abstract (English)*

Using multiple antennas at both the base station (BS) side and the mobile station (MS) side in order to improve systems' capacity has been in the core interest of intensive research effort among the wireless research community. This effort resulted in incorporating Multiple-Input Multiple-Output (MIMO) technologies in emerging wireless broadband standards like long-term evolution advanced (LTE-A). Recently, a lot of research has been devoted to study the performance improvement that can be achieved when the number of antennas at the BS is scaled up to 100 or even few 100s of antennas known as massive MIMO systems [1]. Hence, the extra degrees of freedom gained from the massive MIMO units will improve the system performance.
Due to the availability of lots of frequency-duplexing (FDD) spectrum and the advantage of avoiding synchronization between cells, and consequently avoiding strong interference, it would be great if today's FDD systems could use massive MIMO as an add-on without changing much (if anything) in the standard. Therefore, the aim of this project is to develop transmission algorithms for FDD massive MIMO systems that utilize the directional properties of the wireless channel without the need of feedback information. The project consists of the following two stages:
First, intensive propagation measurement-based studies will be performed in order to understand the effect of having massive number of antennas at the BS (i.e., higher angular resolution) on the directional characteristics of the radio channel experienced by the massive MIMO system. We would like to emphasise the difference between the definitions of the propagation channel and radio channel. The former describes the distribution of the multipath components due to the structure of the physical propagation environment, and the later describes how these multipath components are seen by the communication system. In this work, measurements will be used to understand how the characteristics of the radio channel change over frequency (i.e., between uplink and downlink bands) when the system's high directional resolution is considered.
Second, directional-based transmission algorithms which utilize the directional properties of the propagation channel will be developed. Specifically speaking, in this work, we aim at introducing transmission techniques for massive MIMO systems such that:
1) No extra complexity is added at the MS side. This can be done by developing directional-based beamforming transmission techniques at the BS that don't require any processing at the MS side and at the same time, they don't require any special feedback information. For example, based on the channel properties extracted from the uplink, if the BS decides to communicate with the intended user by transmitting the signal in more than one direction (i.e., beam), then the BS is supposed to adjust its transmission parameters such that those beams are added constructively at the MS.
2) No tough synchronization requirement is added to the system. This can be done by utilizing the directional similarity of the FDD uplink and downlink channels in order to get the required channel state information (CSI) instead of operating in the time-duplexing (TDD) mode.

Popular scientific description (Swedish)*

Trådlösa kommunikationssystem står inför ökade krav på snabbare hastigheter och ökad genomströmning på grund av utökad användning och kapacitetskrävande applikationer. Det begränsade frekvensspektrum som finns tillgängligt medför svårigheter i att uppnå de önskvärda överföringshastigheter som krävs. Användandet av multipla antenner vid en eller båda sidor av kommunikationslänken, även känt som multiple-input multiple-output (MIMO), har visat sig vara en av de mest lovande teknikerna för att bidra med ökad kapacitet och bättre prestanda. Nyligen har en stor del av forskningen varit tillägnad åt att studera den prestandaförbättring som kan uppnås när antalet antenner vid basstationen (BS) skalas upp till flera hundratals, vilket kan kallas storskalig MIMO-system. Genom att ha ett sådant stort antal antennelement är det inte bara möjligt att nå de datahastigheter som krävs, utan skulle även kunna göra systemet grönare genom en minskad utstrålad effekt.
Dagens trådlösa system kan delas upp i två olika kategorier beroende på om systemet utnyttjar tidsduplexering (TDD) eller frekvensduplexering (FDD). System som bygger på FDD använder ofta ett frekvensband för att sända information nedströms från basstationen till användarna. Ett annat frekvensband används för trafiken uppströms, från användarna till basstationen. För TDD används ett frekvensband för att sända signaler inom alternerande tidsintervall, såväl uppströms som nedströms. Det här projektet kommer att fokusera på FDD av följande anledningar: För det första så kräver TDD en strikt tidssynkronisering av nätverket och användarna, och för det andra så har system baserade på FDD implementerats i en mycket större utsträckning jämfört med TDD i dagens trådlösa system.
Generellt sett ombesörjer en basstation flera användare samtidigt. När basstationen kommunicerar med en specifik användare så ser den till att data sänds och tas emot från den användaren och dels ser den till att dessa utsända signaler inte stör ut de signaler som sänds till och från andra användare. För att kunna tillhandahålla en sådan lösning krävs det att basstationen på förhand har någon slags kännedom om hur de utsända signalerna kommer att se ut när de tas emot av den tilltänkta användaren såväl som av de övriga användarna. Det som krävs är information om radiokanalens tillstånd, även kallat Channel State Information (CSI). De olika föreslagna transmissionsteknikerna för storskalig MIMO-system bygger på olika krav och antaganden gällande hur systemet ska kunna tillgodogöra sig CSI av tillräckligt god kvalitet.
Utbredningskanalen avser inom trådlös kommunikation det fysiska medium i vilket signalen utbreder sig från sändaren till mottagaren. Detta inkluderar påverkan från byggnader, gator och trafik. När signalen färdas från sändaren till mottagaren så fördelas signalen inte likformigt i alla riktningar; istället färdas merparten av effekten längs vissa specifika riktningar på grund av utbredningsmiljöns egenskaper. Ett typiskt exempel på detta är gator, som kan fungera som vågledare, vilket tvingar en stor del av den utsända effekten att färdas längs gatukanjoner. Ett annat exempel gäller fall då stora byggnader finns i närheten av sändare och/eller mottagaren, vilket kan medföra att en stor del av den utsända effekten reflekteras bort från byggnader i en viss riktning. I tätbebyggda områden är påverkan från byggnader mer uttalad, särskilt om basstationen sitter placerad på en höjd som är lägre än takhöjden.
Målet med det här projektet är att bidra i utvecklingen av adekvata transmissionstekniker för basstationer med ett stort antal antennelement. I det här projektet drar vi nytta av det faktum att frekvensbanden i FDD-system för kommunikation uppströms och nedström har liknande riktningsegenskaper, och utnyttjar denna information för att tillhandahålla CSI åt basstationen. I det här fallet kommer basstationen att ta emot signaler uppströms från användarna, analysera dem och extrahera värdefull information om deras riktningsegenskaper. De extraherade riktningsegenskaperna är direkt relaterade till karakteristiken hos utbredningsmiljön, såsom byggnaders egenskaper och hur de är fördelade. Tekniken som kommer att utvecklas kan benämnas som riktningsbaserad beamforming, m.a.o., signalerna kommer att fokuseras i vissa spatiala riktningar som tillåter kommunikation med den tilltänka användaren, samtidigt som vissa andra riktningar undviks för att inte störa ut andra användare.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Deductible time

Deductible time

Cause	Months

Career age: 57

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*

2. Teknik > 202. Elektroteknik och elektronik > 20204. Telekommunikation

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

Keyword 1*

massive MIMO

Keyword 2*

FDD MIMO

Keyword 3*

MIMO channel characterization

Keyword 4

Keyword 5

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*

Not applicable

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Downlink Transmission in FDD Massive MIMO Systems based on Uplink Directional Properties

1: PURPOSE AND AIMS

Using multiple antennas at both the base station (BS) side and the mobile station (MS) side in order to improve systems' capacity has been in the core interest of intensive research effort among the wireless research community. This effort resulted in incorporating Multiple-Input Multiple-Output (MIMO) technologies in emerging wireless broadband standards like long-term evolution advanced (LTE-A). Recently, a lot of research has been devoted to study the performance improvement that can be achieved when the number of antennas at the BS is scaled up to 100 or even few 100s of antennas known as massive MIMO systems [1]. Hence, the extra degrees of freedom gained from the massive MIMO units will improve the system performance.

Due to the availability of lots of frequency-duplexing (FDD) spectrum and the advantage of avoiding synchronization between cells, and consequently avoiding strong interference, it would be great if today's FDD systems could use massive MIMO as an add-on without changing much (if anything) in the standard. Therefore, the aim of this project is to develop transmission algorithms for FDD massive MIMO systems that utilize the directional properties of the wireless channel without the need of feedback information. The project consists of the following two stages:

First, intensive propagation measurement-based studies will be performed in order to understand the effect of having massive number of antennas at the BS (i.e., higher angular resolution) on the directional characteristics of the radio channel experienced by the massive MIMO system. We would like to emphasise the difference between the definitions of the propagation channel and radio channel. The former describes the distribution of the multipath components due to the structure of the physical propagation environment, and the later describes how these multipath components are seen by the communication system. In this work, measurements will be used to understand how the characteristics of the radio channel change over frequency (i.e., between uplink and downlink bands) when the system's high directional resolution is considered.

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2) No tough synchronization requirement is added to the system. This can be done by utilizing the directional similarity of the FDD uplink and downlink channels in order to get the required channel state information (CSI) instead of operating in the time-duplexing (TDD) mode.

It is of *extreme* importance to emphasise the following two points:

1) Even though in this project we propose to use FDD, obtaining the required CSI at the BS-Tx will *not* be done in the traditional FDD way. In this project, feedback will *not* be used to provide the BS-Tx with the required CSI, so there will be *no* CSI feedback bits sent from the MS. However, the BS will be able to obtain the required directional CSI based only on the directional properties of the multipath clusters extracted from the uplink MS signals.
2) Throughout this project, we do *not* make any claim that the suggested directional-based beamforming transmission techniques using FDD systems will outperform transmission techniques that depend on perfect CSI knowledge using TDD systems. However, for several practical reasons, FDD represents a better option. For example: a) FDD does not impose strict synchronization requirement on the network, b) FDD does not require reciprocity calibration, and c) operators as well as manufacturers prefer the FDD option due to its immediate compatibility with current band assignment and already built handsets.

2: SURVEY OF THE FIELD

Scaling up the number of antennas at BS to hundreds and making the ratio between the number of BS antennas and the number of served MS to be around 10 to 1 provides the system with very large degrees of freedom. This large number of degrees of freedom gives massive MIMO systems the potential of obtaining huge improvement to the power and spectral efficiency of wireless systems [1, 2], as well as designing HW-friendly signal shaping and estimating the channel using smart receiver algorithms [3, 4].

Measurements have shown that when the number of BS antennas increases significantly, the system experiences a favourable propagation condition [5]. Initial measurements proved the possibility of achieving close to the theoretical promised MIMO capacity in multi-user scenarios using large number of BS antennas [6]. However, this capacity can be achieved only in the case when both the BS-Tx and the MS-Rx know the channel perfectly (i.e., full CSI). While getting the full CSI at the MS-Rx can be done relatively easily using training sequences, obtaining the full CSI at the BS-Tx not only represents a real challenge, but it is also crucial to achieve the highest possible capacity. Generally, there are two possible methods to provide the BS-Tx with the full CSI depending on whether the system is time-duplexing (TDD) or frequency-duplexing (FDD).

In TDD systems, getting the full CSI relies on the notion of reciprocity, where the uplink channel is used as an estimate of the downlink channel. In practice, system imperfections such as calibration error in the downlink/uplink RF chains, and hardware impairment limit the performance of TDD massive MIMO systems. Discussing these imperfections and the proposed methods to mitigate them is out of the scope of this proposal. Besides that, in TDD, precise timing and synchronization is required at both the Tx and Rx to make sure time slots don’t overlap or otherwise interfere with one another. Compared to TDD, FDD on the other hand provides the flexibility of reducing the synchronization requirement. In this proposal, we will focus on FDD systems due to their high importance for both operators and manufacturers and their dominance in current wireless cellular systems.

In FDD systems, the downlink and uplink use different frequency bands. In this case, the BS transmits orthogonal pilots (one pilot per BS antenna), and then the MS sends a feedback reporting the CSI to the BS. This method is not an option when considering large MIMO systems, because: 1) in the downlink, an unrealistic number of pilots is required, which scales up with the number of the BS antenna elements, and 2) on the uplink, an impractically large fraction of available bandwidth is required in order to feedback the CSI between all BS antennas and each MS. Different approaches are discussed in [7, and the references therein] to reduce the feedback cost in FDD massive MIMO systems based on utilizing the second order statistics of the channel.

Despite the high directional resolution that can be gained from using massive number of antenna elements at the BS, to the best of our knowledge, there is no study that tried to utilize the directional properties of the wireless channel (specifically speaking, on the *multipath clusters* level as explained in the next section) in order to estimate the downlink channel (or a subset of its parameters) based on the uplink channel in massive MIMO systems, which is the main focus of our proposal.

3: PROJECT DESCRIPTION

Radio signals propagate from the Tx to the Rx over multiple different propagation paths, resulting in the reception of multiple multipath components (MPCs). Each MPC can be characterized by its power, phase, angle of departure (AoD), angle of arrival (AoA) and delay. Propagation measurement results have shown that the MPCs are not received uniformly in the spatio-temporal space. Instead, energy is concentrated in clusters associated with reflections, scattering, and diffraction by interacting objects. Clusters have been defined in the literature as accumulations of MPCs that have similar spatio-temporal parameters (e.g., AoD, AoA and delay) and share the same long term evolution, i.e., they stay intact over time [8, 9, 10].

The characteristics of these clusters are directly related to both the signal properties, the nature of the propagation environment, and the properties of the interacting objects located between and around both the Tx and the Rx. Significant directional properties of the propagation channel can be extracted from the received signal regardless of its frequency. Of course the aforementioned statement is *not* unconditionally valid; however, in this project we can argue that it is valid because the difference in the frequencies between the uplink and the downlink bands (which is typically on the order of 100 MHz) is small enough such that we can assume that the interaction with the objects in the propagation environment results in (almost) the same *directional* properties at the two bands. For example, it is guaranteed to have the same AoA, AoD, and delay of each MPC at both bands (given that the high-frequency ray approximation is equally valid in both bands). If resolving the individual MPCs is not possible (which is the case when considering the resolution of practical systems), the system deals with clusters instead of individual MPCs. Therefore, due to the constructive or destructive addition of MPCs within each cluster, the instantaneous power, AoA, AoD, and delay of each cluster are different at the two bands because each MPCs has different phase in each band.

During the last year, we have carried out initial studies to investigate the mismatch in directional properties between uplink and downlink channels of FDD systems based on comparing the structure of their multipath clusters. The investigation was carried out using:

- The commercial ray tracing tool ‘Wireless InSite’, where the 3D model of downtown, Helsinki, was used for simulations. The BS was fixed in an open area in the middle of the city model, at a height of 20 m from the ground. A set of locations were selected for the Rx in the form of routes. The operating frequency was around 2.6 GHz with a variable duplex distance (between 5 MHz and 120 MHz).
- Channel measurements using a uniform cylindrical array with 128 antenna elements were performed at the campus of Lund University, Sweden. The 128-element cylindrical array acted as a base station positioned at the top of a 5-floor building, and a few single-antenna users were distributed around the base station.

A ‘Spectral Similarity Metric’ (D_{SSM}) was used to compare uplink and the downlink channels based on the structure of their multipath clusters. This metric is given by [11]:

$$D_{SSM} = \left\{ \sum_{c=1}^{C} \left| S_{c,UL} - S_{c,DL} \right| \right\} \Big/ \left\{ \sum_{c=1}^{C} S_{c,UL} + \sum_{c=1}^{C} S_{c,DL} \right\}$$

where, C denotes the total number of considered clusters, $S_{c,UL}$ the power of the c^{th} cluster of the uplink, and $S_{c,DL}$ the power of the c^{th} cluster of the downlink. The range of this metric is from 0 to 1. For clusters carrying similar power level in uplink and downlink, D_{SSM} will be 0, whereas in the case of full mismatch, D_{SSM} will be 1.

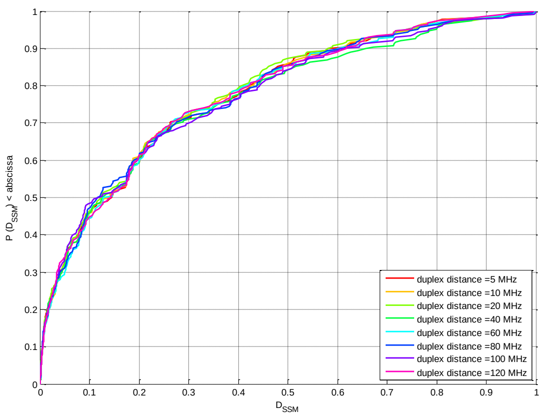

Fig. 1. Plot of CDF of spectral similarity metric for ray-tracing simu-lated data for all receiver locations, and all duplex distances.

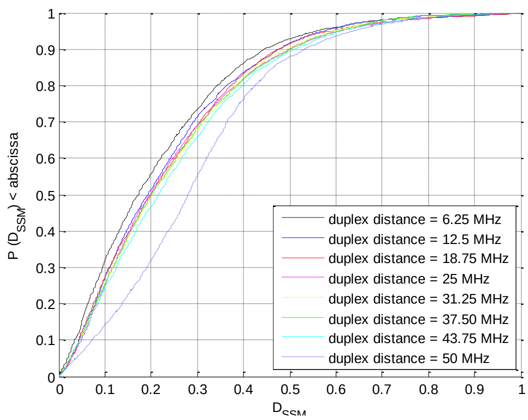

Fig. 2. Plot of CDF of spectral similarity metric from measurement data.

Fig. 1. and Fig. 2 depict the cumulative distribution function (CDF) of the spectral similarity metric for ray-tracing simulated data, and measurement data, respectively. We can deduce from these figures that: 1) for 50% of the receiver locations, the structure of the multipath clusters in the uplink and downlink show very high similarity (D_{SSM} < 0.20), and 2) the effect of the considered duplex distances, which was between 5 MHz and 120 MHz, is insignificant on the similarity of the uplink and downlink multipath clusters. Furthermore, the sum-rate capacity of multi-user systems (with different user intensities) using directional information estimated from the uplink was compared with the sum-rate capacity calculated by using the actual downlink channel parameters and the difference was found not be more than 14% in all considered cases [12].

One of the proposed approaches is to utilize the high directional resolution, gained from having arrays with massive number of elements, in order to reduce the effect of the constructive and destructive addition of the MPCs within each perceived cluster to the point that the main parameters (power and phase) of at least some clusters at the downlink band can be estimated with reasonable error from the uplink band. This approach stands on two facts:

1. A cluster from the wireless channel point-of-view (e.g., reflections from an interacting object such as a wall) may be *perceived* as more than one cluster by the massive MIMO system due to the high angular resolution of the massive array and/or its large physical size. Therefore, the system will perceive the signal reflected from one interacting object as several clusters each of which includes the MPCs that interact with only a specific section of the interacting object. (e.g., each section of the wall is associated with a cluster).
2. The narrower the beam, the smaller the number of the MPCs within each cluster, and therefore, the smaller the runtime difference among these MPCs; consequently, the higher the K-factor of the clusters. If the K-factor is reasonably high, the parameters of the signal of each cluster will be *less random*:
   a) The envelope will have a Gaussian PDF with a mean which is proportional to the strength of the cluster and a standard deviation proportional to the strength of the diffused components [13, page 126]:

$$f_R(r) = \frac{1}{\sqrt{\pi P_{non-spec}}} e^{-\frac{(r-V_{spec})^2}{P_{non-spec}}},$$

$$K = \frac{Specular\ power}{Nonspecular\ power} = \frac{(V_{spec})^2}{P_{non-spec}},$$

   where, r is the envelope of the signal, . See Fig. 3.

   b) The phase, depending on the value of the K-factor, will have a Gaussian-like PDF with a spread that is inversely proportional to the value of the K-factor [14, page86]:

$$f_\emptyset(\varphi) = \frac{1+\sqrt{\pi K} e^{K\cos(\varphi)^2} cos(\varphi)(1+erf[\sqrt{K}cos(\varphi)])}{2\pi e^K},$$

   where, φ is the phase of the signal, and $\text{erf}(x)$ is the error function. See Fig. 4.

Based on the details of the interacting object associated with each cluster, only clusters with sufficiently high K-factor will be utilized.

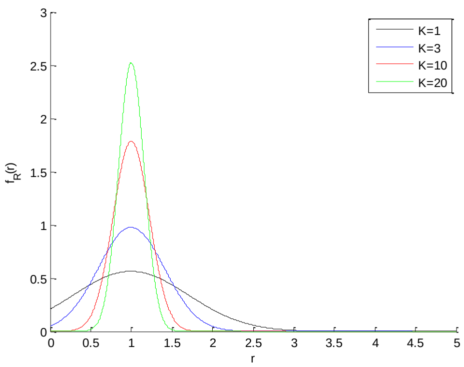

Fig. 3. PDF of the envelop (r) of a non-zero mean Gaussian distribution, with $K = 1, 3, 10,$ and 20. $mean(r) = 1$.

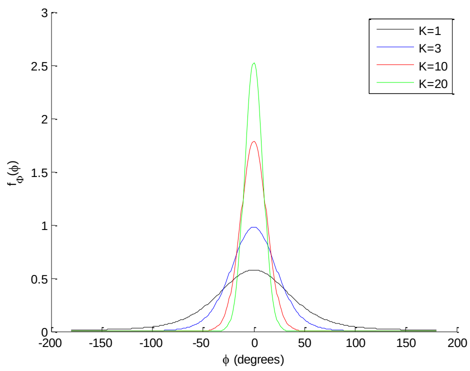

Fig. 4. PDF of the phase (φ) of a non-zero mean Gaussian distribution, with $K = 1, 3, 10,$ and 20.

In order to have initial investigation toward verifying the above mentioned approach, indoor measurements using a Vector Network Analyser (VNA) were performed. The setup of the measurements was as follows:

- Bandwidth = 200 MHz, at the 5.2 GHz band, where 1601 frequency bins were measured (i.e, $\Delta f = 125\ KHz$).
- One Tx element was used, and at the Rx a virtual uniform linear array (ULA) with 31 elements was used (inter-element spacing is $\lambda/2$).
- NLOS conditions; the signal reached the Rx after being reflected on a wall that have some windows.
- An additional smooth metal board (about 2×0.8 m) was placed in the environment to act as a good reflecting interacting object.

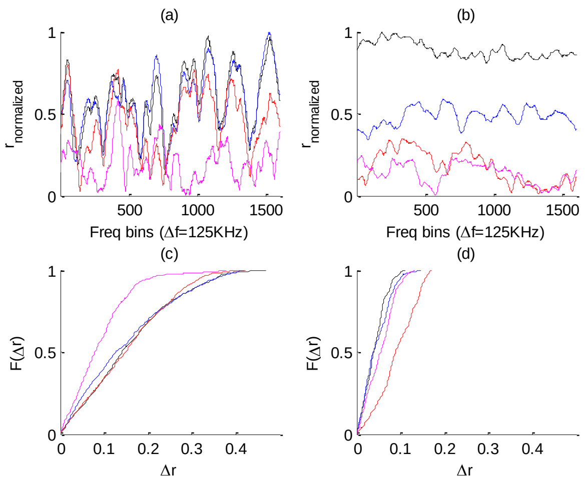

Fig. 5. Variation of the amplitude (r) of the signal of four clusters throughout a band of 200 MHz. Each cluster is depicted with the same color in all subfigures. (a) and (c): using ULA with 5 elements. (b) and (d): using ULA with 31 elements. (a) and (b): change of the envelop. (c) and (d): Empirical Cumulative Distribution Function of the change of the envelop, where $\Delta r = |r - mean(r)|$, r is normalized such that $max(r) = 1$.

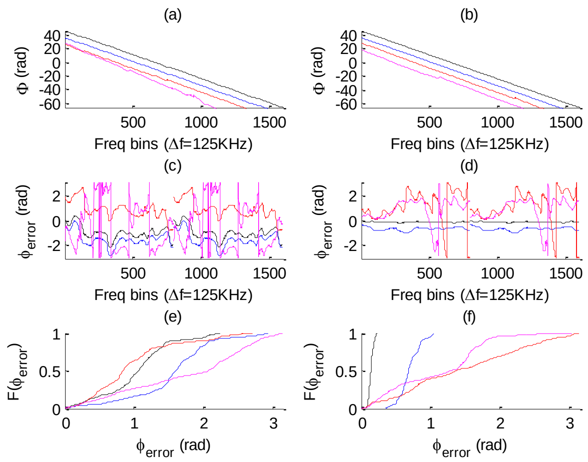

Fig. 6. Variation of the phase of the signal of four clusters throughout a band of 200 MHz. Each cluster is depicted with the same color in all subfigures. (a), (c), and (e): using ULA with 5 elements. (b), (d), and (f): using ULA with 31 elements. (a) and (b): change of the phase. (c) and (d): phase estimation error assuming a duplex distance of 100 MHz. (e) and (f): ECDF of the phase estimation error assuming a duplex distance of 100 MHz.

The analysis of the data was performed as follows: 1) The signals received from four specific directions have been identified as four clusters, and 2) conventional beamforming was performed at the Rx in these four directions, first by using a subset of the Rx elements (ULA with 5 elements), and second by using all the available Rx elements (ULA with 31 elements). These conventional beamformers were performed in all 1601 frequency bins (taking into consideration the frequency-dependent characteristics of the steering vectors), which covers the 200 MHz measured bandwidth. Then the amplitudes and the phases resulting from these four beamformers have been extracted to study there variations over the 200 MHz bandwidth (Fig.5 - 6).

- Variations of the *amplitude* of the measured clusters (i.e., beams). From Fig. 5., it can been seen that: 1) the higher the directional resolution, the more stable the amplitude of the four clusters, compare Fig. 5(a), and (b), 2) when the directional resolution of the beams is high (using the ULA with 31 elements), in almost 90% of the cases the relative variation of the strongest three clusters (black, blue and red) is less than 10%.

- Variations of the *phase* of the measured clusters (i.e., beams). Fig. 6. (a) and (b), shows how the phases of the signals of the four clusters change as a function of frequency within the 200 MHz measured band. Fig. 6(b) shows that using a ULA with 31 elements the result is clusters that have signals that exhibit almost linear phase throughout the whole 200 MHz band. Then a very simple phase compensation algorithm was applied to check the possibility of estimating the phases of these clusters in the downlink band based on their phases in the uplink band as follows. The first 10 MHz of the measurement data was utilized to estimate the slope of these lines (i.e., $change\ in\ phase\ /\ change\ in\ frequency$), then, based on the estimated slope, the phase of each cluster was estimated at the downlink based on its phase at the uplink assuming a duplex distance of 100 MHz. Fig. 6(f) shows that, when ULA with 31 elements is used, the phases of the strongest cluster (black) can be estimated with error not more than 0.22 rad. (13 degrees), and the phase of the second strongest cluster (blue) can be estimated with error not more than $\pi/4$ rad. (45 degrees) in 70% of the cases. However, for the other two clusters, the result is much worse than that.

Based on the discussion and results presented earlier, the framework of this proposal targets the following points:

Task 1 (Year 1-2): Investigating the uplink-downlink directional mismatch

Ray-tracing software and propagation measurements will be used to investigate the expected improvement in the performance of non-cooperative multicellular systems when the directional information is used as the basis of multiplexing the different users.

Main focus: Performing detailed analysis that targets answering the following questions:

1- What is the effect of the distribution of the buildings and their properties (e.g., height, size) on the expected improvement? In other words, does each pattern of buildings generate rich multipath clusters that make space-division multiplexing a winning transmission strategy?
2- How can we optimize the height and location of the BSs?
3- What is the optimal antenna geometry that can be used? What is more suitable: using antenna arrays with large aperture (e.g., uniform linear array), or using antenna arrays with small aperture and better (or different) directional properties (e.g., uniform cylindrical array, or 2D array geometry)?
4- How can we minimizing the error between the directional CSI (i.e, the direction, power, and phase of each cluster of interest), which is extracted from the uplink, and the actual ones in the downlink? In other words, how can we compensate for the frequency/wavelength difference between the uplink and the downlink channels *on the multipath clusters level*?

Given the known limitations of ray-tracing software in capturing all the details of the wireless channel, ray-tracing software will be used to address only points 1, 2, and 3 which are related to the distribution of the clusters in the directional domain. On the other hand, point 4, which deals with the spatio-tempral behaviour of the individual clusters, will be addressed exclusively based on propagation measurements.

Task 2 (Year 3-4): Developing transmission techniques based on the uplink directional properties

At the beginning, a conventional beamformer, where the weights of the antenna elements are not adaptively updated, will be considered. At this step, we will assume a quasi-static channel and the goal will be to utilize the directional information which is collected from the uplink in order to improve the system's performance by steering the beam toward the intended users and nulling the directions of detected interference. Different approaches will be used in order to appropriately synthesize the beam-pattern using different cost functions.

The ultimate developed transmission techniques will be able to form *environment-aware* multiple-beams in the direction of the intended users (such that, with correctly estimating the phase of each beam, they will be added constructively at the intended users positions) as well as forming nulls in the direction of interferers. The developed algorithms should also be adaptive to both: the dynamics of the users and the dynamics of the environment. The developed algorithms will be able to adapt the transmission scheme frequently and utilize the directional information of each user to predict its future location (direction).

Main focus: Developing transmission techniques with the following two criterions:

1- Optimizing the usage of physically large arrays. Given that the statistics of the received signal varies at the different positions within the antenna array when antenna arrays with large aperture are considered, and given the available large degree of freedom in such arrays, how can we optimize the directional beamforming transmission techniques? For example, should the transmission techniques deal with the array as a single array with very large number of antennas, or should it be divided into independent small sub-arrays?
2- Taking advantage of history of the channel. For example, utilizing the relatively slow update of the directional information in order to predict the present/future state i.e., future direction and location of each user.

<u>4: EQUIPMENT / MEASUREMENTS</u>

The department of electrical and information technology has the most advanced experimental equipment for MIMO channel measurements, putting it into a unique position to successfully conduct the research program of this project. The cornerstone of the laboratory equipment is the RUSK LUND channel sounder. It is a fast switched broadband MIMO channel sounder covering frequencies 5.1-5.8 GHz, 2.2-2.7 GHz and 235-387 MHz (and in the coming year it will be upgraded to work at the 15 GHz band). The sounder can perform dynamic measurements and manage up to 32x128 channels in various antenna configurations with a maximum bandwidth of 240 MHz. It can also be used to perform measurement with up to 9 single-element MSs, connected by means of radio-over-fiber. At the department we also have a virtual array setup based on a vector network analyzer and antenna positioners that is useful for detailed and specific studies in static environments.

The Department of Electrical and Information Technology offers a fully equipped research radio laboratory with all facilities necessary to design advanced equipment including integrated analog, digital and high frequency circuits. Any necessary calibrations of the measurement equipment and the sounder and measurement antennas can be done in the anechoic chamber of the group, which allows measurements in the frequency ranges of interest for this proposal.

5: SIGNIFICANCE

The main contribution of this research is to look at alternative techniques to solve channel related issues for FDD massive MIMO systems without the need for the full CSI. The goal is to make the BSs being able to get the required CSI based on the similarity of the directional properties of both the uplink and the downlink bands by taking advantage of the massive number of the antenna elements at the BS. The results of this project represents an effort to shift the focus away from studying the effect of the large number of antenna elements on the statistics of the entries of the channel matrix, and focus instead on studying the uplink and the downlink channels on the level of multipath clusters and their directional properties. This project represents a significant and essential research work to investigate key issues related to massive MIMO and its utilization in 5G.

6: INDEPENDENT LINE OF RESEARCH

Currently, I work as a postdoc researcher in the following two projects: 1) Distributed antenna systems for efficient wireless systems (DISTRANT) [www.eit.lth.se/index.php?puid=157&L=1], and 2) Massive MIMO for Efficient Transmission (MAMMOET) [www.http://mammoet-project.eu]. The goal of these projects is to explore the potential benefits of using two diverse base station multi-antenna arrangements that are considered to be candidates for 5G. In both projects, my research duties are related to the measurements, characterization and modelling of the wireless channels. If this proposal is accepted, it will give me the time and financial resources to investigate different ideas regarding FDD massive MIMO systems.

7: FORM OF EMPLOYMENT

My current contract with Lund University will end in Aug. 2016. My work load is divided to: research (about 90%), and teaching (about 10%), where I teach a graduate course titled "Channel modelling for wireless communications". I also co-supervise Ph.D. students (two students), and supervise master students (four students). After the end of my contract, I expect to be involved in other projects in the department. If this proposal is accepted, it will help me to secure fulltime employment as a researcher.

References

[01] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, "Scaling up MIMO: opportunities and challenges with very large arrays," *IEEE Magazine on Signal Processing*, vol. 30, no. 1, pp. 40-46, January 2013.

[02] H. Ngo, E. Larsson and T. Marzetta, "Energy and Spectral Efficiency of Very Large Multiuser MIMO Systems", *IEEE Transactions on Communications*, vol. 61, no. 4, pp. 1436-1449, April 2013.

[03] S. Mohammed and E. Larsson, "Per-antenna Constant Envelope Precoding for Large Multi-User MIMO Systems", *IEEE Transactions on Communications*, vol. 61, no. 3, pp. 1059-1071, March 2013.

[04] E. Larsson, and F. Tufvesson, Tutorial, "Very Large MIMO Systems", *37th International Conference on Acoustics, Speech, and Signal Processing (ICASSP) 2012*, Kyoto, Japan , March 26, 2012, [online], available: http://www.commsys.isy.liu.se/~egl/vlm/vlm.html]

[05] S. Payami, and F. Tufvesson, "Channel measurements and analysis for very large array systems at 2.6 GHz," *6th European Conference on Antennas and Propagation, EuCAP 2012*, Prague, Czech Republic, March 26-30, 2012.

[06] X. Gao, F. Tufvesson, O. Edfors, and F. Rusek, "Measured propagation characteristics for very-large MIMO 2.6 GHz," *46th Annual Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, California, USA, November 4-7, 2012.

[07] Z. Jiang, A. Molisch, G. Caire, and Z. Niu, "Achievable rates of FDD massive MIMO systems with spatial channel correlation," *IEEE Transactions on Wireless Communications,* [doi: 10.1109/ TWC.2015. 2396058]

[08] M. Toeltsch, J. Laurila, K. Kalliola, A. Molisch, P. Vainikainen and E. Bonek, "Statistical characterization of urban spatial radio channels," *IEEE Journal on Selected Areas in Communications*, vol. 20, no. 3, pp.539-549, April 2002.

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[10] H. Asplund, A. Glazunov, A. Molisch, K. Pedersen, and M. Steinbauer, "The COST 259 directional channel model part II: macrocells," *IEEE Transactions on Wireless Communications*, vol. 5, no. 12, pp. 3434–3450, December 2006.

[11] S. Imtiaz, G. Dahman, F. Rusek, and F. Tufvesson, "On the Directional Reciprocity of Uplink and Downlink Channels in Frequency Division Duplex Systems," *IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, Washington DC, USA, September 2-5. 2014.

[12] S. Imtiaz, "*Uplink-Based Downlink Beamforming in Frequency Division Duplex Systems*," Msc thesis, Lund University, Lund, 2012.

[13] Gregory D. Durgin, *Space-time wireless channels*. Prentice Hall Professional, 2011.

[14] Andreas F. Molisch, *Wireless communications*. John Wiley & Sons, 2007.

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	Ghassan Dahman	20
2	Other personnel without doctoral degree	PhD student	85

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Ghassan Dahman	20	148,000	153,000	157,000	162,000	620,000
2	Other personnel without doctoral degree	PhD Studenst	85	445,000	459,000	472,000	487,000	1,863,000
	Total			593,000	612,000	629,000	649,000	2,483,000

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

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Travel	Travel/Conferences	40,000	40,000	40,000	40,000	160,000
2	Equipment and software	Equipment and software	90,000	20,000	20,000	20,000	150,000
3	Lokalkostnad	Lokalkostnad (11%)	80,000	74,000	76,000	78,000	308,000
4	OH	OH (31%)	224,000	208,000	214,000	220,000	866,000
	Total		434,000	342,000	350,000	358,000	1,484,000

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	593,000	612,000	629,000	649,000	2,483,000		2,483,000
Running costs	434,000	342,000	350,000	358,000	1,484,000		1,484,000
Depreciation costs					0		0
Premises					0		0
Subtotal	1,027,000	954,000	979,000	1,007,000	3,967,000	0	3,967,000
Indirect costs					0		0
Total project cost	1,027,000	954,000	979,000	1,007,000	3,967,000	0	3,967,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

The budget will be spent on the following:
1- Salaries (20% main applicant, and 85% for a PhD student)
2- Around 40000 a year cost for travel and conferences
3- Equipment and software: buying ray-tracing sofware, and HW parts, antennas, cables, ... for performing the measurements.
4- The costs of the OH and the Lokalkostnad are listed above.

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 FOR GHASSAN DAHMAN

MASTER DEGREE(S)

New Mexico State University, NM, USA.. .... (1999-2001)

Degree: Master of Science in Electrical Engineering (Communications and DSP)
Thesis title: Object Detection and Localization in Compressed Video
Supervisor: Dr. Charles Creusere

New Mexico State University, NM, USA.. .... (1999-2001)

Degree: Master of Art in Extension Education
Supervisor: Dr. Carlos Rosencrans

DOCTORAL DEGREE

Carleton University, Ottawa, Canada .... (Jan. 2005- June 2010)

Degree: Ph.D. in Electrical and Computer Engineering (Wireless Communications)
Thesis title: Multi-Antenna Mobile Radio Channels: Modelling and System Performance Predictions
Supervisors: Dr. Roshdy Hafez (Carleton U.), and Dr. Robert Bultitude (CRC)

PROFESSIONAL/RESEARCH EXPERIENCE

Department of Electrical and Information Technologies, Lund University, Lund, Sweden

POSTDOC RESEARCHER .... AUG. 2012 - PRESENT

PROJECTS: "DISTRIBUTED ANTENNA SYSTEMS FOR EFFICIENT WIRELESS SYSTEMS", AND "MASSIVE MIMO FOR EFFICIENT TRANSMISSION"

- Exploring the potential benefits of using two diverse base station multi-antenna arrangements that are considered to be candidates for 5G: distributed antennas, and massive MIMO. In both projects, my research duties are related to the measurements, characterization and modelling of the wireless channels.
- Teaching a graduate course titled "Channel Modelling for Wireless Communications".

Department of Elecrtical Engineering, Umm Al-Qura University, Makkah, Saudia Arabia

ASSISTANT PROFESSOR .... SEP. 2010 - JULY 2012

- Taught courses in the field of communications and digital signal processing.
- Contributed throughout the different phases of the ABET accreditation process for the Electrical Engineering program at UQU including: developing courses syllabuses, analyzing students' outcomes, and preparing the self-study reports.

Communications Research Center(CRC), Ottawa

RESEARCHER .... 1 JUNE 2010 - 31 AUG. 2010

Analyzed double-directional propagation measurements, conducted in downtown Ottawa by the CRC, and modelled the time-varying characteristics of multipath clusters in MIMO wireless channels.

Canspect Corporation, Ottawa, Canada

PROJECT COORDINATOR (Part-Time; while pursuing the PhD degree) .. .NOV. 2005 –DEC. 2007

Coordinated and followed up industrial inspections through the different production stages including: ensuring the effective preparation and production of all necessary documentation; taking responsibility for the effective flow of information between suppliers, clients, and inspectors, and performing regular evaluation of project activity and reporting on project progress.

Publication list

Publication List

JOURNAL PUBLICATIONS

- **G. Dahman**, J. Flordelis, and F. Tufvesson, " Analysis of Multi-Link Large-Scale Parameters in a Suburban Micro-Cellular Environment," to be submitted to *IEEE Tran. on Wireless Comm.*
- **G. Dahman**, F. Rusek, M. Zhu, ans F. Tufvesson, "On the probability of non-shared multipath clusters in cellular networks," accepted, *IEEE Wireless Communications Letters.*
- **G. Dahman**, R. Hafez, and R. Bultitude "Angle-of-departure-aided opportunistic space-division multiple access for MIMO applications". *IEEE Tran. on Wireless Comm,* vol. 9, no. 4, pp. 1303 – 1307, 2010.
- **G. Dahman**, R. Bultitude, and R. Hafez, "The use of frequency-orthogonal pseudo-noise (FOPN) sounding signals for identifying transmissions from different transmit antennas," *IEEE Antennas and Wireless Prop. Letters,* vol. 8, pp. 657-60, 2009.
- H. Bouchekara, M. K. Smail, and **G. Dahman**, "Diagnosis of Multi-Fault Wiring Network Using Time-Domain Reflectometry and Electromagnetism-Like Mechanism," *Electromagnetics*, Vol. 33, no. 2, pp. 131-143, 2013.

CONFERENCE PUBLICATIONS

- **G. Dahman**, J. Flordelis, and F. Tufvesson, "Experimental Evaluation of the Effect of BS Antenna Inter-Element Spacing on MU-MIMO Separation," accepted, *IEEE International Conference on Communications, ICC,* London, UK, June 8-12, 2015.
- J. Flordelis, X. Gao, **G. Dahman**, F. Rusek, O. Edfors and F. Tufvesson, "Spatial Separation of Closely-Spaced Users in Measured Massive Multi-User MIMO Channels," accepted, *IEEE International Conference on Communications (ICC),* London, UK, June 8-12, 2015.
- S. Imtiaz, **G. Dahman**, F. Rusek, and F. Tufvesson, "On the Directional Reciprocity of Uplink and Downlink Channels in Frequency Division Duplex Systems," *IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, Washington DC, USA, September 2-5. 2014.
- **G. Dahman**, J. Flordelis, and F. Tufvesson, "On the cross-correlation properties of large-scale fading in distributed antenna systems," *IEEE Wireless Comm. and Networking Conference, WCNC,* Istanbul, Turkey, April 6-9, 2014.
- J. Flordelis, **G. Dahman**, and F. Tufvesson, "Measurements of Large-Scale Parameters of a Distributed MIMO Antenna System in a Microcell Environment At 2.6 GHz," *7th European Conference on Antennas and Propagation, EuCAP*, Gothenburg, Sweden, April 8-12, 2013.
- R. Bultitude, **G. Dahman**, and R. Hafez, "Using frequency-orthogonal pseudonoise (FOPN) sounding sequences to identify signals from multiple transmit antennas in mobile double-directional and relay channel sounding systems," *URSI*, Istanbul, Turkey, Aug. 2011, pp. 1-4.
- **G. Dahman**, R. Bultitude, and R. Hafez, "Evaluation of the communications performance achievable on base station to handheld-terminal radio links with several different practical receive antenna arrays," *IEEE Saudi International Electronics, Communications and Photonics Conference (SIECPC)*, Riyadh, Saudi Arabia, Apr. 2011, pp. 1-6.
- **G. Dahman**, R. Bultitude, and R Hafez, "Identifying and modelling multipath clusters using measurement data," *IEEE 72nd Vehicular Technology Conference (VTC)*, Ottawa, Canada, Sep. 2010, pp 1-5.
- **G. Dahman**, R. Hafez, and R. Bultitude, "A Cluster-Based Spatial Opportunistic Spectrum Sharing Technique for Cognitive Radio Applications," *IEEE 72nd Vehicular Technology Conference (VTC),* Ottawa, Canada, Sep. 2010, pp 1-5.
- R. Bultitude, **G. Dahman**, R. Hafez, and H. Zhu, "Double directional radio propagation measurements and radio channel modelling pertinent to mobile MIMO communications in microcells," *IEEE International Conference on Wireless Information Technology and Systems (ICWITS),* Honolulu, HI, USA, Aug. 2010, pp. 1-4.

- **G. Dahman** and R. Hafez, “Angle-of-departure-aided opportunistic space-division multiple access,“ ***Won The Best Paper Award*** in the *7th annual Communications Networks and Services Research (CNSR)*, Moncton, NB, Canada, May, 2009, pp. 146-152.
- **G. Dahman**, R. Bultitude, and R Hafez, “A method for identifying simultaneously-transmitted signals from different transmit antennas in multi-antenna channel sounding experiments,” *24th Biennial Symposium on Communications (QBSC)*, Kingston, ON, Canada, June, 2008, pp. 179 - 181.
- C. Cruesere and **G. Dahman**, “Object detection and localization in compressed video,” *35th Asilomar Conference on Signal, Systems, and Computers*, Pacific Grove, CA, USA, Nov. 2001, pp. 93 - 97.

CONFERENCE ABSTRACTS AND PRESENTATIONS

- **G. Dahman**, R. Bultitude, R. Hafez, and Y. DeJong, " Estimation and Analysis of Single-Directional Multipath Information from 2.25 GHz PN Sounder Measurements using a Mobile 32 Element Receive Array and a Simulated Single-Antenna Microcellular Base Station in Downtown Ottawa", *URSI*, Ottawa, ON, Canada, July 2007.

CONTRIBUTIONS TO COST IC1004 (PRESENTATIONS, NONE PEER REVIEWED PAPERS)

- **G. Dahman**, J. Flordelis, and F. Tufvesson, “Effect of BS Antenna Inter-Element Spacing on the Correlation of the Parameters of Common Clusters: Initial Investigation,” *COST IC1004*, Dublin, Ireland, Jan. 28-30, 2015.
- J. Flordelis, X. Gao, **G. Dahman**, F. Rusek, O. Edfors and F. Tufvesson, “Spatial Separation of Closely-Spaced Users in Measured Massive Multi-User MIMO Channels,” Dublin, Ireland, Jan. 28-30, 2015.
- J. Flordelis, **G. Dahman**, and F. Tufvesson, “On the Coherence Time of Fiber-Based Distributed Antenna Systems,” *COST IC1004*, Aalborg, Denmark, May 26-28, 2014.
- **G. Dahman**, J. Flordelis, and F. Tufvesson, “Analysis of Multi-Links Large-Scale Parameters in Suburban Micro-Cellular Environments,” *COST IC1004*, Aalborg, Denmark, May 26-28, 2014.
- **G. Dahman**, J. Flordelis, and F. Tufvesson, “Cross-correlation properties of large-scale parameters in multi-link distributed antenna systems: synchronous measurements versus repeated measurements,” *COST IC1004*, Ferrara, Italy, Feb. 5-7, 2014.
- **G. Dahman**, F. Rusek, M. Zhu, and F. Tufvesson, “On the probability of non-shared clusters in cellular networks,” *COST IC1004*, Ferrara, Italy, Feb. 5-7, 2014.
- **G. Dahman**, J. Flordelis, and F. Tufvesson, “On the cross-correlation properties of large-scale fading in distributed antenna systems,” *COST IC1004*, Ghent, Belgium, Sep. 25-27, 2013.

CV

Name: Ghassan Dahman	**Doctorial degree:** 2010-06-01
Birthdate: 19731201	**Academic title:** Doktor
Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)
Multi-Antenna Mobile Radio Channels: Modelling and System Performance Predictions

Dissertation title (en)
Multi-Antenna Mobile Radio Channels: Modelling and System Performance Predictions

Organisation	Unit	Supervisor
Carleton University, Canada Not Sweden - Company		Roshdy Hafez

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20204. Telekommunikation	978-0-494-67872-5	2010-06-01

Publications

Name: Ghassan Dahman	**Doctorial degree:** 2010-06-01
Birthdate: 19731201	**Academic title:** Doktor
Gender: Male	**Employer:** No current employer

Dahman, Ghassan 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.