

NES

Networked and
Embedded Systems



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FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN



Heading for the Future

From left to right

Mario Huemer

Professor and Dean

Christian Bettstetter

Professor and
Institute Head

Bernhard Rinner

Professor and
Vice Institute Head

Information and communication technology is one of the most significant forces driving technical and economic progress throughout the world. ICT systems are part of our daily lives both at work and at home: We communicate via mobile phones, enjoy multimedia entertainment via the Internet, and share digital photos and videos with our families and friends. The world has become increasingly networked. A latest trend is that ICT systems are more and more hidden in objects in daily use – they are literally «embedded» and make these gadgets smart. Tiny sensors, for instance, are embedded into clothes to monitor vital signs. It takes highly trained and creative engineers to generate such innovations. They develop new ideas, products, and services to make life simpler and more comfortable.

What is NES?

The Institute of Networked and Embedded Systems (NES) at the University of Klagenfurt contributes toward this trend by performing cutting-edge research and teaching in this domain. Research and teaching areas include wireless communications and networking, sensor and camera networks, signal processing, and autonomous aerial robot systems. A special focus is set to self-organizing systems, where Lakeside Labs clusters the expertise on this emerging topic in Klagenfurt.

A distinctive research and teaching culture

We are indeed proud of our development: Since its foundation in 2007, the NES institute has grown to almost 50 staff members – now being the largest research and teaching unit in Klagenfurt. With more than 40 % of researchers from abroad, we offer a truly international and multicultural environment. Our research portfolio includes both basic science and applied research, where the annual third-party volume reaches two million Euros, and the number of publications exceeds 40 journal and conference articles per year. Staff members received best paper awards and were short listed and offered positions by international top universities.

Teaching takes into account the fast and continuous changes typical for the world of ICT, where knowledge is quickly outdated. Students enjoy wide and well-founded education and are trained to think analytically and grasp complex interrelationships. NES offers core courses of the bachelor program «Informations-technik» and the follow-up master and programs in English. It also participates in the international program «Interactive and Cognitive Environments», Austria's first Erasmus Mundus doctorate program.

This brochure gives an overview of the NES institute. We report on a patented technique saving energy in high-rate communications, flying robots supporting disaster response forces, and nature-inspired algorithms solving self-organizing network synchronization, to name a few topics. It also highlights our teaching portfolio as well as our technical infrastructure situated at the Lakeside Science and Technology Park.



FRIEDERIKE WALL

Vice President for Research

The Institute of Networked and Embedded Systems has an excellent research record. This is all the more remarkable considering the fact that it was founded only a few

years ago. I sincerely want to congratulate all members of the institute and am convinced that their future development will be equally positive.



HANS SCHÖNEGGER

Kärntner Wirtschaftsförderungs Fonds

Within only a few years the Institute of Networked and Embedded Systems succeeded in achieving remarkable visibility

on the international research map. The highly engaged professors Bettstetter, Huemer, and Rinner attract an international crowd of researchers and thus essentially contribute to Carinthia being a top location for high-tech research and development.



Energy Management for Mobile Devices

Selected Publications

M. Agostinelli, R. Priewasser, S. Marsili,
M. Huemer

Fixed-frequency pseudo sliding mode control for a buck-boost DC-DC converter in mobile applications: a comparison with a linear PID controller. IEEE Intern. Symp. Circuits and Systems (ISCAS), Brazil, 2011.

M. Agostinelli, R. Priewasser, M. Huemer,
S. Marsili, D. Straeusnigg

SystemC-AMS modeling and simulation of digitally controlled DC-DC converters. IEEE Appl. Power Electron. Conf. (APEC), USA, 2010.

R. Priewasser, M. Agostinelli, S. Marsili,
M. Huemer

Digital controller design for point-of-load DC-DC converters with variable switching frequency. IET Electronics Letters, 2011.

R. Priewasser, M. Agostinelli, M. Huemer,
S. Marsili

Digitally-controlled DC-DC converter with variable switching frequency. IEEE Intl. Conf. Electron., Circuits., Syst. (ICECS), Greece, 2010.

The growing demand of features introduced in mobile devices – smartphones, laptops, e-book readers, and digital cameras – causes an increase in the number of components integrated in such systems. Such components are displays, processing units, transceivers, and others that need to be powered by the battery. «Each component requires a proper supply voltage or even a number of different voltages to remain stable independent of the battery charge status and the system operating conditions,» Matteo Agostinelli explains.

To provide supply voltage of the required quality, a dedicated power management unit is essential. The attempt to minimize the energy needed for conversion poses a special challenge in the design of power management units. One or more DC-DC converters are needed to adjust the voltage generated by the battery. Commonly, step-down converters (output voltage is lower than battery voltage) and step-up converters (output voltage is higher than battery voltage) are required.

Concepts for such converters have been developed by a team of Klagenfurt researchers in a third-party funded project with Infineon. The most promising solutions have been verified by hardware prototypes. Designed with a 0.13 μm high-voltage CMOS technology, several test chips have been manufactured.



Wireless Communications with Relays

Selected Publications

H. Adam, C. Bettstetter, S. M. Senouci

Adaptive relay selection in cooperative wireless networks. IEEE Intern. Symp. Personal, Indoor Mobile Radio Commun. (PIMRC), France, 2008.

H. Adam, W. Elmenreich, C. Bettstetter, S. M. Senouci

CoRe-MAC: A MAC protocol for cooperative relaying in wireless networks. IEEE GLOBECOM, USA, 2009.

H. Adam, E. Yanmaz, C. Bettstetter

Contention-based estimation of neighbor cardinality. IEEE Trans. Mobile Comput., 2012.

C. Bettstetter, G. Brandner, R. Vilzmann

On colliding first messages in slotted ALOHA. IEEE Intern. Symp. Personal, Indoor Mobile Radio Commun., France, 2008.

G. Brandner, U. Schilcher, T. Andre, C. Bettstetter

Packet delivery performance of simple cooperative relaying in real-world car-to-car communications. IEEE Wireless Commun. Lett., 2012.

Cooperative relaying is a novel technique for wireless communications promising gains in throughput and energy efficiency of mobile systems. The basic idea sounds simple: A device transmits a data signal to a destination. A third device overhears this transmission and relays the signal to the destination as well. Finally, the destination combines the two received signals to improve decoding.

This concept gives rise to pure wireless self-organizing networks without any need for base stations. It can be employed in various applications of networked embedded systems. Cars use it to communicate directly with each other, for instance, to exchange reports on accidents, traffic jams, or bad road conditions. Autonomous robots may use it to build a wireless network in areas without infrastructure, e.g., in deserts and in space.

«Using communication techniques where devices cooperate to transmit signals over the air exploits a new, distributed form of spatial diversity that mitigates the negative effects of signal fading and interference,» states Christian Bettstetter. As a result, battery life is extended and electromagnetic radiation is diminished.

A team of six NES researchers around Bettstetter has been working on this topic for four years. They have made various scientific advances.

The task of relay selection is an important building block to realize cooperative relaying in practice. Devices located between sender and potential receiver must agree in a distributed manner as to which of them will act as relay and thus promote wireless communication. To perform this task, Helmut Adam developed a relay selection protocol that is backwards compatible to the

N. Marchenko, E. Yanmaz, H. Adam,
C. Bettstetter

Selecting a spatially efficient cooperative relay.
IEEE GLOBECOM, USA, 2009.

N. Marchenko, C. Bettstetter

Cooperative multicast with low-cost radios.
IEEE Veh. Technol. Conf. (VTC), Canada, 2010.

N. Marchenko, C. Bettstetter

Throughput and energy efficiency of
cooperative diversity with relay selection.
Europ. Wireless, Austria, 2011.

N. Marchenko, C. Bettstetter

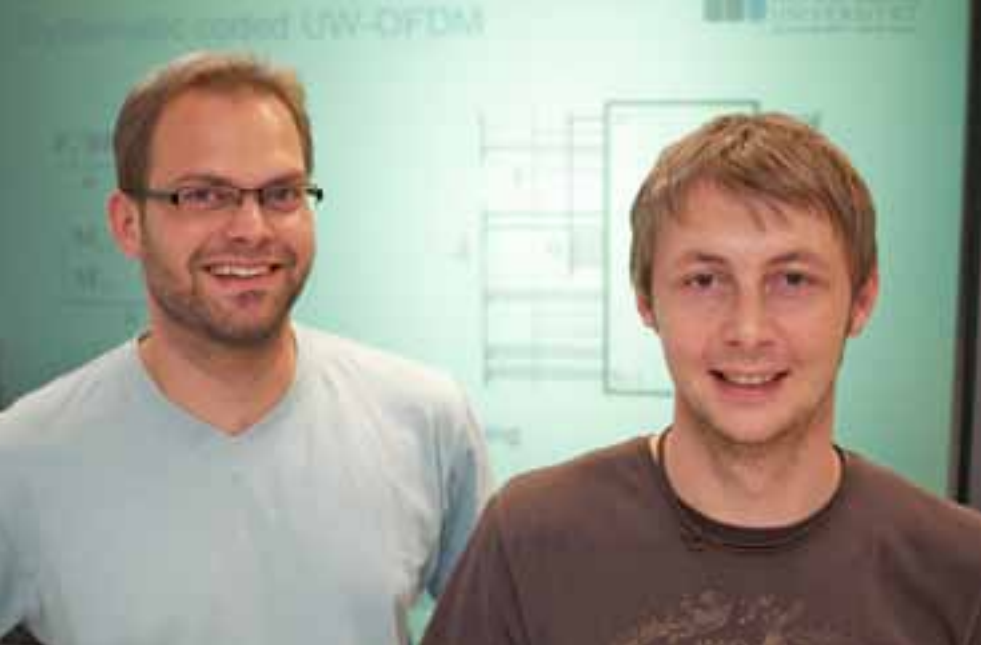
Impact of relay selection overhead in
cooperative diversity protocols.
IEEE Veh. Technol. Conf. (VTC), USA, 2011.



standard IEEE 802.11 WLAN protocol. In collaboration with Orange Labs, France, he specified this protocol and filed its main ideas in two patents. An inherent feature of his approach is a method that estimates the number of potential relays around a sender.

His colleague, Nikolaj Marchenko, takes a more theoretical approach. He uses Markov chains to model and evaluate relaying protocols taking into account the achieved throughput as well as the required energy and signaling traffic for communications. «My goal is to find the best-suited relaying technique for a particular environment, and I am also exploiting cooperative relaying for multicast communications», he says.

The NES research, however, exceeds mathematical models and equations. Results have been implemented and tested in real-world setups. A programmable hardware platform is employed to perform measurements in vehicle surroundings and in industrial halls. «These measurements reveal as to which scenarios our relaying solution yields an improved performance compared to existing techniques,» researcher Günther Brandner points out. Developing such a prototype is sometimes very demanding. All three lower layers of the protocol stack have to be programmed on an FPGA-based board. The researchers believe that their solutions within this Lakeside Labs project will be implemented into standards and products.



High-Rate Communications using UW-OFDM

Selected Publications

M. Huemer, C. Hofbauer, A. Onic, J. B. Huber

On the exploitation of the redundant energy in UW-OFDM: LMMSE versus sphere detection. IEEE Signal Process. Lett., 2012.

M. Huemer, C. Hofbauer, J. B. Huber

Non-systematic complex number RS coded OFDM by unique word prefix. IEEE Trans. Signal Process., 2012.

M. Huemer, A. Onic, C. Hofbauer

Classical and Bayesian linear data estimators for unique word OFDM. IEEE Trans. Signal Process., 2011.

The dominating technique for high data rate communications in wired and wireless applications is Orthogonal Frequency Division Multiplexing (OFDM). It is used in WLAN, DSL Internet access, digital video broadcast, and LTE networks, to give some examples. State-of-the-art OFDM systems, however, consume up to 20 % of the transmit energy and data rate for a «guard interval» that is needed to cope with the negative effects of multi-path propagation.

Researchers at NES invented a novel scheme, called Unique Word OFDM, which replaces the guard interval with a predefined sequence. Compared to classical OFDM schemes, this «unique word» can be exploited to improve synchronization and estimation at the receiver. Furthermore, correlations introduced by this novel signaling paradigm either substantially decrease the bit error rate or save transmit energy.

«Reducing energy consumption is of great interest to end users. All smart phone users wish to extend battery life,» states Alexander Onic, one of two PhD candidates in Klagenfurt. Together with colleagues from Erlangen-Nuremberg, they have been working on this topic for the past four years. His professor, Mario Huemer, aims high: «Unique Word OFDM has the potential to be implemented in future mobile devices. We recently filed a patent on its basic idea.»



Interference Dynamics in Wireless Networks

Selected Publications

C. Bettstetter, M. Gyarmati, U. Schilcher

An inhomogeneous node distribution and its stochastic properties. *ACM/IEEE Intern. Symp. Modeling, Analysis, Sim. Wireless Mobile Syst. (MSWIM)*, Greece, 2007.

U. Schilcher, M. Gyarmati, C. Bettstetter, Y. W. Chung, Y. H. Kim

Measuring inhomogeneity in spatial distributions. *IEEE Veh. Technol. Conf. (VTC)*, Singapore, 2008.

U. Schilcher, G. Brandner, C. Bettstetter

Diversity schemes in interference-limited wireless networks with low-cost radios. *IEEE Wireless Commun. Netw. (WCNC)*, Mexico, 2011.

U. Schilcher, C. Bettstetter, G. Brandner

Temporal correlation of interference in wireless networks. *IEEE Trans. Mobile Comput.*, 2012.

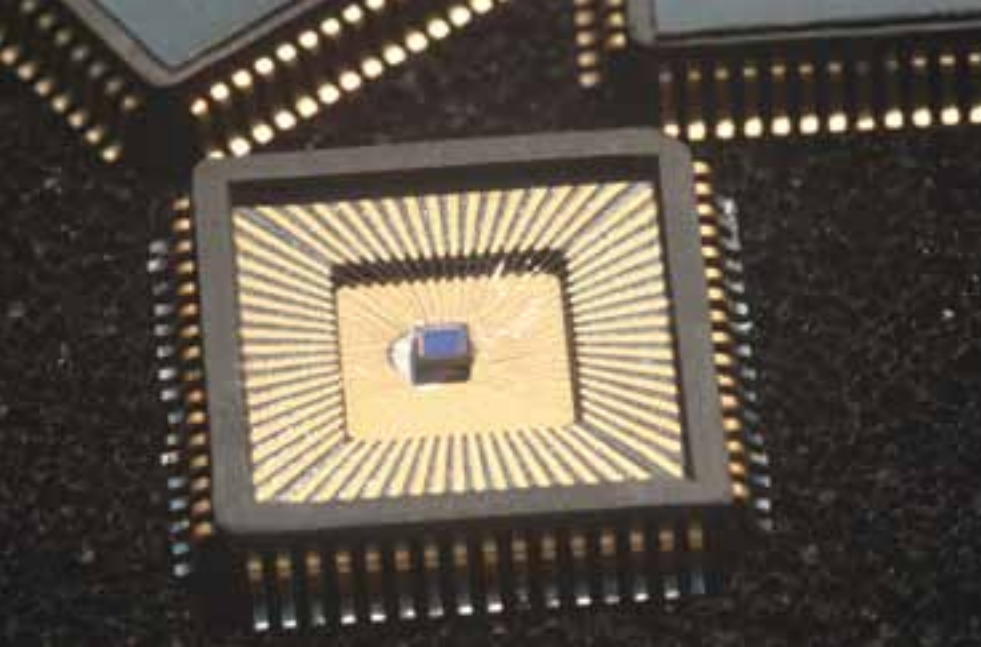
In mobile communications, simultaneous transmission of several devices may lead to interference causing some transmissions to fail and sent information to be lost. Due to the ever-increasing density of mobile devices and base stations, handling interference becomes more and more important.

Mature technologies, such as GSM, try to avoid interference completely by using reserved channels for each communication. Today's WLANs in turn reserve a «transmission floor» around a communicating pair of devices to avoid interference as far as possible and employ retransmission protocols in case packets are nevertheless lost. In new technologies – with help of modern signal processing techniques and multiple antenna systems – interference will basically be allowed but then be mitigated at the receiver.

The performance of all these techniques is, however, influenced by how interference behaves over time. «Immediate retransmission of unreceived data makes no sense if interference persists,» explains Udo Schilcher. «A transmission is more likely to succeed under improved interference conditions.»

He and his professor, Christian Bettstetter, jointly aim at gaining a deep understanding of interference dynamics in the time and space domain and to rigorously analyze its impact on system performance. A key challenge is to express the correlation of interference in terms of mathematical equations. Using such expressions, the team intends to advance interference mitigation techniques and test them in a real-world setup with programmable mobile devices.

This basic research has been awarded with a three-year funding contract from the Austrian Science Fund FWF.



Integrated Signal Processing Systems

Selected Publications

C. Lederer, M. Huemer

LMS based digital cancellation of second-order TX intermodulation products in homodyne receivers. IEEE Radio Wireless Symp. (RWS), USA, 2011.

T. Schlechter, M. Huemer

Advanced filter bank based approach for blocker detection in LTE systems. IEEE Intern. Symp. Circuits Syst. (ISCAS), Brazil, 2011.

A. Weiss, A. Onic

A fit-to-sine based processing chain to handle multiple-target scenarios. Radar Conference (EURAD), France, 2010.

Signal processing is nowadays used in nearly every electronic device, from mobile phones over medical appliances to cars. The research and development process of a signal processing system typically starts with system-level modeling and simulation. Next, algorithmic solutions are studied and compared with respect to performance and implementation complexity. The implementation platform (e.g. ASIC, FPGA, or DSP) depends on various aspects, such as system complexity and energy consumption. After choosing the algorithms and a suitable platform, the overall implementation architecture is designed, the hardware-software-split is defined, and optimizations are performed. Finally, the system is implemented in software and/or hardware and integrated into the targeted application.

«A detailed knowledge in signal processing theory combined with a solid expertise in hardware-software principles is key for the development of efficient signal processing systems,» PostDoc Michael Lunglmayr points out.

Mario Huemer has been working on this topic for more than ten years. He successfully completed various research projects in cooperation with Infineon Technologies, Intel, EADS, and NXP Semiconductors. «The broad expertise on embedded systems and signal processing in our group makes us a valuable partner for companies in the semiconductor and electronics industry,» he states. «These cooperations are win-win situations: Companies benefit from our broad expertise, and we gain access to the latest semiconductor technologies and to highly topical industrial know-how. Our students have the chance to get in touch with potential employers.»



Resource Configuration in Sensor Networks

Selected Publications

B. Dieber, C. Micheloni, B. Rinner

Resource-aware coverage and task assignment in visual sensor networks. *IEEE Trans. Circuits Syst. Video Technol.*, 2011.

L. Esterle, P.R. Lewis, M. Bogdanski, B. Rinner, X. Yao

A socio-economic approach to online vision graph generation and handover in distributed smart camera networks. *ACM/IEEE Intern. Conf. Distr. Smart Cameras*, Belgium, 2011.

C. Micheloni, B. Rinner, G. L. Foresti

Video analysis in PTZ camera networks – From master-slave to cooperative smart cameras. *IEEE Signal Process. Mag.*, 2010.

B. Rinner, B. Dieber, L. Esterle, P.R. Lewis, X. Yao

Resource-aware configuration in smart camera networks. *IEEE Workshop Camera Networks Wide Area Scene Analysis*, USA, 2012.

Wireless sensor networks are typically used to monitor buildings, agricultural areas, and other remote environments. In most applications, the monitoring tasks have to be performed within quality constraints with limited computing and energy resources. The large number of sensors compensates for the lack of processing power of single sensors and allows the network to fulfill complex jobs. However, in many cases, task coordination within the network is required to provide monitoring quality and reasonable network lifetime at the same time.

In current sensor networks, tasks are being coordinated manually or semi-automatically. This is infeasible in large or remote networks. More sophisticated and automatic configuration methods are required, where tasks adapt to the environmental situation to provide context-sensitive monitoring. Bernhard Dieber, a researcher at NES, explains: «Some sensors focus on movement detection first and then change to person tracking. When changing to a new task, we must consider the resources needed to perform it.» Image resolution, frame rate, and complexity of the processing tasks influence the resource consumption. Dieber develops a distributed approach for dynamic reconfiguration that achieves intended network operation with minimal resources.

Similar research topics are also investigated in the multi-disciplinary project EPICS funded by the European Commission in the Future and Emerging Technologies program. Lukas Esterle and Bernhard Rinner collaborate with the University of Birmingham to develop methods for resource-aware tracking handover in camera networks. Their socio-economic approach applies auction mechanisms to control the tracking resources in highly dynamic environments. Recently, Esterle and Dieber merged their approaches into a holistic framework for resource-aware reconfiguration of visual sensor networks.



Small-Scale UAV Systems

Selected Publications

M. Quaritsch, E. Stojanovski, C. Bettstetter,
G. Friedrich, H. Hellwagner, B. Rinner,
M. Hofbaur, M. Shah

Collaborative microdrones: Applications and research challenges. Intern. Conf. Auton. Comput. Commun. Syst. (Autonomics), Italy, 2008.

D. Wischounig-Strucl, M. Quaritsch, B. Rinner

Prioritized data transmission in airborne camera networks for wide area surveillance and image mosaicking. IEEE Workshop Camera Netw. Wide Area Scene Analysis, USA, 2011.

S. Yahyanejad, D. Wischounig-Strucl,
M. Quaritsch, B. Rinner

Incremental mosaicking of images from autonomous, small-scale UAVs. IEEE Intern. Conf. Adv. Video Signal-Based Surveill. (AVSS), USA, 2010.

S. Yahyanejad, M. Quaritsch, B. Rinner

Incremental, orthorectified and loop-independent mosaicking of aerial images taken by micro UAVs. IEEE Intern. Symp. Robotic Sensors Environ., Canada, 2011.

Small-scale unmanned aerial vehicles (UAVs) are considered with increasing interest in civil and commercial applications. Equipped with cameras and other sensors, these aerial robots can quickly sense the environment from a bird's eye view. This supports first time responders in case of disasters – flooding, mudslide, forest fire, and earthquake – to quickly assess the situation and coordinate action forces.

Being part of the research cluster Lakeside Labs, a team of seven researchers and four professors in Klagenfurt develops a system that provides functionality similar to Google Earth and Microsoft Virtual Earth but capturing small areas with much higher resolution: A user first outlines the area of interest on a map. The UAVs fly over the specified area, take images, and provide an accurate and up-to-date overview picture of the environment.

«Our solution requires mission planning and coordination for multiple aerial vehicles,» explains senior researcher Markus Quaritsch. The system computes the flight routes for the individual UAVs taking into account the maximum flight time due to battery constraints. A flight route consists of a sequence of waypoints specified in GPS coordinates, the flight altitude, and a set of actions for every waypoint such as taking a photo, setting orientation. The UAVs autonomously fly according to the computed plan without any need for human interaction.

The UAVs are equipped with different sensors (e.g., thermal camera, conventional photo camera) to build a multi-layered overview image. The pictures taken are pre-processed on board the UAV and sent to the ground station during flight. At the ground station the individual pictures are mosaicked to a large overview image. The pictures show significant perspective distortions due to the low altitude of less than 150 m. NES has

E. Yanmaz, R. Kuschnig, C. Bettstetter

Channel measurements over 802.11a-based UAV-to-ground links. Intern. Workshop Wirel. Netw. Unmanned Autonom. Veh., USA, 2011.

E. Yanmaz

Connectivity versus area coverage in unmanned aerial vehicle networks. IEEE Intern. Conf. Commun. (ICC), Canada, 2012.

E. Yanmaz, M. Quaritsch, R. Kuschnig, S. Yahyanejad, D. Wischounig-Strucl, V. Mersheeva, G. Friedrich, H. Hellwagner, C. Bettstetter, B. Rinner

Collaborative small-scale multi-UAV systems.



developed and patented an incremental approach for computing the overview picture that provides quick feedback to the user and is geometrically correct and visually appealing at the same time.

Another aspect is the wireless communication between ground station and UAV. Evsen Yanmaz performs research in this domain. «Our real-world experiments showed that off-the-shelf WLAN systems lead to poor performance. Some antenna modifications made the system work,» she explains. Furthermore, a prioritized transmission scheme based on multi-resolution compression enables the system to send a low-resolution version of the picture immediately after it was taken and high-resolution parts as the available data rate permits.

The real-world applicability of the system is a major objective. It was demonstrated several times in coordinating fire fighters performing service drills. «We recently participated in a large-scale forest fire exercise in the Austrian-Slovenian border region,» Quaritsch says. «Other demonstrations included the monitoring of a large construction site near Vienna and the observation of an industrial accident». The lessons learned by such applied research will further the work of a recently founded spin-off company.



Privacy-Aware Smart Cameras

Selected Publications

A. Doblander, A. Zoufal, B. Rinner

A novel software framework for embedded multiprocessor smart cameras.

ACM Trans. Embedded Comput. Syst., 2009.

B. Rinner, W. Wolf

Introduction to distributed smart cameras.

Proc. IEEE, 2008.

B. Rinner, T. Winkler, W. Schriebl, M. Quaritsch, W. Wolf

The evolution from single to pervasive smart cameras. Intern. Conf. Distribut. Smart Cameras (ICDSC), USA, 2008.

T. Winkler, B. Rinner

Applications of trusted computing in pervasive smart camera networks. Workshop Embedded Syst. Security (WESS), France, 2009.

T. Winkler, B. Rinner

TrustCAM: security and privacy-protection for an embedded smart camera based on trusted computing. Intern. Conf. Advanced Video and Signal-Based Surveillance (AVSS), USA, 2010.

Surveillance cameras have found their way into many parts of our daily lives. While monitoring public places – airports, train stations, and sports stadiums – is still the predominant use case, applications are more and more expanding into private environments as well. Such widespread adoption of camera networks, however, raises severe privacy concerns, since recorded video sequences usually contain sensitive data such as people’s faces, their interaction and behavior patterns as well as their personal preferences.

«The central aspect is to protect all sensitive data before it leaves the camera,» Thomas Winkler, a researcher in Rinner’s group, points out. «We can use the computing power in modern camera systems not only for video analysis but also for onboard privacy protection. This was realized in the design of our Trust-CAM prototype.»

The system implements a multi-level privacy solution where even legitimate system operators get access only to behavioral information while protecting the identities of persons. The difficulty is to find the right balance between system utility and adequate privacy protection. Accessing the original video is possible solely by virtue of the four-eye-principle.

To be able to provide adequate privacy protection, NES researchers decided not to rely on software security solutions only but to adopt ideas from the field of trusted computing. Their hardware-based security concept integrates a dedicated microchip into the camera providing secure storage of cryptographic keys, system status monitoring and reporting, and a unique device identity. It guarantees for authenticity, integrity, and confidentiality of data delivered by the camera.

T. Winkler, B. Rinner

A systematic approach towards user-centric privacy and security for smart camera networks. Intern. Conf. Distribut. Smart Cameras (ICDSC), USA, 2010.

T. Winkler, B. Rinner

Securing embedded smart cameras with trusted computing. EURASIP J. Wireless Commun. Netw., 2011.

T. Winkler, B. Rinner

User centric privacy awareness in video surveillance. Multimedia Systems, 2012.



To raise public acceptance, the researchers designed a system that enables people to independently assess whether a camera implements appropriate privacy protection and security measures. Communication between people's smart-phones and cameras is initiated using visual communication techniques which eliminate certain attack scenarios of radio-based channel establishment.

Even though preliminary results are promising and have been well accepted by the scientific community, research on privacy and security in camera networks is still at an early stage. Future work will focus on integrating protection techniques directly into the image sensors. This will be the next step towards the vision of inherently privacy-preserving and trustworthy camera networks.



Engineering Self-Organizing Systems

Selected Publications

W. Elmenreich, R. D'Souza, C. Bettstetter,
H. de Meer

A survey of models and design methods for self-organizing networked systems. Intern. Workshop Self-Organizing Syst. (IWSOS), Switzerland, 2009.

I. Fehervari, W. Elmenreich

Evolving neural network controllers for a team of self-organizing robots. J. Robotics, 2010.

R. Holzer, H. de Meer, C. Bettstetter

On autonomy and emergence in self-organizing systems. Intern. Workshop Self-Organizing Syst. (IWSOS), Austria, 2008.

C. Prehofer, C. Bettstetter

Self-organization in communication networks: Principles and design paradigms. IEEE Commun. Mag., 2005.

A. Sobe, W. Elmenreich, L. Böszörményi

Towards a self-organizing replication model for non-sequential media access. ACM Multimedia Workshop, Italy, 2010.

Self-organization can be observed in nature by looking at the successful coordination within insect states, schools of fish, and flocking birds. In such systems, many components (sometimes hundreds or thousands) follow a set of simple local rules that eventually lead to an emergent global behavior. These principles are robust, scalable, and adaptive, thus being an important measure toward handling the increasing number of networked components in today's ICT systems.

Despite the simple interaction among the components, designing technical systems that follow the same principles as nature poses an enormous challenge to engineers. Lakeside Labs researchers are elaborating concepts, methods, and tools for engineering self-organizing systems.

«Evolution created natural self-organizing systems, which is why we opt for the same path,» explains project leader Wilfried Elmenreich. His team works on evolving systems that employ an automated search systematically developing the fittest solution. To support such evolutionary design, the open-source tool FREVO has been developed and applied for experimental studies in social behavior, robot soccer, and area exploration.

Another topic is covered by PostDoc Anita Sobe: «A system ready to be deployed has to be maintainable. It should not require expert knowledge to fix a broken part.» She develops a middle-ware solution that intends to minimize the effort for configuration and maintenance.



Self-Organizing Synchronization

Selected Publications

[J. Klinglmayr](#), [C. Bettstetter](#)

Self-organizing synchronization with inhibitory-coupled oscillators: Convergence and robustness. *ACM Trans. Auton. Adapt. Syst.*, 2012.

[J. Klinglmayr](#), [C. Kirst](#), [C. Bettstetter](#), [M. Timme](#)

Guaranteeing global synchronization in networks with stochastic interactions.

[A. Tyrrell](#), [G. Auer](#), [C. Bettstetter](#)

Fireflies as role models for synchronization in ad hoc networks. *Intern. Conf. Bio-Inspired Models Network, Information, Comput. Syst. (BIONETICS)*, Italy, 2006.

[A. Tyrrell](#), [G. Auer](#), [C. Bettstetter](#)

Emergent slot synchronization in wireless networks. *IEEE Trans. Mobile Comput.*, 2010.

[A. Tyrrell](#), [G. Auer](#), [C. Bettstetter](#), [R. Naripella](#)

How does a faulty node disturb decentralized slot synchronization over wireless networks? *IEEE Intern. Conf. Commun. (ICC)*, South Africa, 2010.

[A. Gogolev](#), [C. Bettstetter](#)

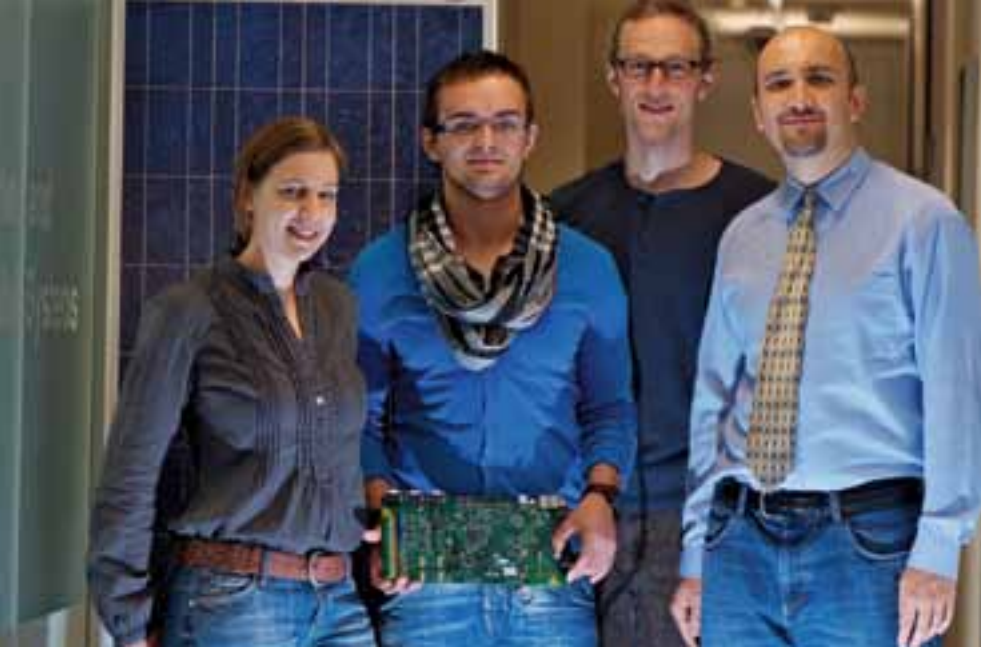
Robustness of self-organizing consensus algorithms: Initial results from a simulation-based study. *Intern. Workshop Self-Organizing Syst. (IWSOS)*, Netherlands, 2012.

The synchronous flashing of fireflies is a spectacular example for self-organization in nature. Thousands of fireflies gather in trees and flash in unison using a distributed mechanism that can be understood by applying the theory of coupled oscillators. This theory has successfully been used for modeling many other synchronization and coordination phenomena, such as sleep cycles, firing of neurons, and vibration of bridges.

«We aim at advancing this field of science and transferring it to technology, in particular to wireless communication networks,» project leader Christian Bettstetter argues. Synchronization is an important building block in large networks of embedded systems, where synchrony should emerge in a distributed manner without having to rely on central entities.

Indeed, the team has developed a solution that works well in wireless systems. It is now being implemented in a programmable hardware platform for field tests. Johannes Klinglmayr is very excited about the results. «Let's see whether measurements in a real-world environment will confirm our promising simulation results,» he says. The young scientist was awarded a € 10,000 scholarship by Austrian Industry to spend a sabbatical at the Max Planck Institute for Dynamics and Self-Organization in Germany.

The team also investigates robustness aspects of self-organization against faulty devices. What happens if one or more devices misbehave in some manner? The idea is to use an approach from neuroscience and combine it with results already obtained. «We have mathematically proven that the resulting algorithm converges,» Klinglmayr proudly concludes. These robustness studies are now generalized to other forms of coordination in networks, such as self-organizing consensus. It is of interest, how communication errors influence the performance of such algorithms.



Smart Microgrids

Selected Publications

W. Elmenreich, D. Egarter

Design guidelines for smart appliances.
Workshop on Intelligent Solutions in
Embedded Systems (WISes), Austria, 2012.

W. Elmenreich

Time-triggered smart transducer networks.
IEEE Trans. Ind. Informat., 2006.

An increasing number of appliances, the advent of electric vehicles, and the awareness that resources are limited pose a challenge to current electric grids. These grids have not changed for decades but now they need to get «smarter».

Smart grids are a combination of power networks and communication networks that allow integration of consumer actions. If using their renewable resources, households and industry sites could become more independent from the larger grid. «Energy consuming entities that are also able to produce energy can be considered as smart microgrids,» says Wilfried Elmenreich.

New challenges arise in a network of smart microgrids: Each smart microgrid can autonomically buy and sell energy. Intelligent algorithms balance the energy load by proposing usage patterns for various appliances, such as washing machines and heating. «The future house equipped with a smart microgrid and a photovoltaic system helps reducing both running costs and environmental compatibility,» predicts physicist Manfred Pöchacker.

In a smart microgrid, many actors need to collaborate at different levels by exchanging energy, information, and capital. Since it is hard to manage such a complex system in a centralized manner, power and communication networks need to be based on self-organization.

The smart grid team funded by Lakeside Labs strives for researching a holistic approach on smart microgrids and acquiring know-how in this area. Researcher Dominik Egarter: «We are establishing a smart microgrid lab where students can gain practical experience.»



CHRISTINA RUSS

The courses offered in our master program are very exciting and don't lack in variety. I feel very supported by the professors and the teaching staff and would very much second the decision of students to study Information and Communication Technology at the University of Klagenfurt.



JENNIFER SIMONJAN

Taking up the study of ICT at the University of Klagenfurt can warmly be recommended to anybody interested in engineering. It offers a wide range of specialization possibilities and I enjoy the professional yet personal atmosphere among teaching staff and students. I chose the NES institute to work on my bachelor thesis since embedded systems are ubiquitous and I'm very interested in their research and developments.



Teaching

NES conducts teaching at the bachelor, master, and PhD levels. Most courses are aimed toward students in ICT but are open to students in informatics and mathematics as well.

The bachelor program trains basic skills in mathematics, physics, electrical engineering, and software development. It also covers electronics and circuits, signals and systems, measurement and control engineering, computer and network technology.

The master program provides substantial knowledge, skills, and methods in ICT. Students not only gain broad knowledge, but can also specialize in one of the areas:

- Control and measurement systems
- Embedded Communications and signal processing
- Intelligent transportation systems
- Mobile communications and networks
- Multimedia systems
- Pervasive computing
- Sensor and actuator systems

The master program is held in English and thus allows international students to join our courses, e.g., via a double-degree program with the University of Udine.

Each professor supervises 10 doctoral students on average. Most of them are employed in research projects or funded by international programs. The doctoral program is individually tailored to the respective research topic, where supervisors act as guides toward the PhD. Students are expected to publish research results in international journals (mainly IEEE and ACM) and present at peer-reviewed conferences.



Infrastructure

The NES institute maintains four research and teaching labs. The pervasive computing lab provides students with the possibility to do hands-on work on smart cameras and sensor networks. The embedded systems lab contains high-precision measurement equipment for analog and digital signals in embedded circuits. The future networking lab gives students the chance to work with advanced equipment in mobile communications, in particular with the software-defined radio platform WARP and with low-power wireless sensor modules. The ICT lab provides the environment for a number of courses and lectures (e.g., embedded microcontroller programming, network simulation, circuit design).

A team of three technicians led by Wilfried Elmenreich takes care of the technical infrastructure. They service the laboratory equipment, handle orders of new hardware, administrate the servers, and maintain a distributed backup strategy. A state-of-the-art HP blade center runs a number of well-managed services:

- Internal Wiki knowledge database
- Request tracking system
- File repositories for collaborative work (SVN and GIT)
- High-performance fileserver
- License servers for MATLAB, IBM Rational, and other packages
- Simulation servers for research and teaching

«Before a paper deadline, our simulation servers are used intensively. If you listen carefully, you can deduce the server load from the noise level of the fans,» explains system administrator Severin Kacianka.



FLORIAN MICHL

Infineon Technologies

It was soon after the foundation of NES that we at Infineon Technologies Villach started co-operations with the institute which are still thriving today. Currently we work together on several PhD topics and have a vivid scientific exchange which has led to a considerable number of joint publications and patents. We wish the NES institute a bright future and hope that they keep attracting global talent to the Wörthersee area!

Cooperation Partners and Funding Agencies

ACCM, Austria	Orange Labs, France
AIT – Austrian Institute of Technology	QM University of London, UK
ASFINAG, Austria	TTTech, Austria
CTR, Austria	University of Birmingham, UK
DMCE, Austria – an Intel subsidiary	University of Central Florida, USA
DOCOMO Euro-Labs, Germany	University of Erlangen-Nuremberg, Germany
EADS, Germany	University of Genua, Italy
EFKON, Austria	University of Linz, Austria
ETH Zürich, Switzerland	University of Notre Dame, USA
FH of Upper Austria	University of Oslo, Norway
Georgia Tech, USA	University of Paderborn, Germany
Graz University of Technology, Austria	University of Porto, Portugal
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Max Planck Institute Göttingen, Germany	European Commission
National University of Singapore	European Science Foundation ESP
NXF Semiconductors Austria	Kärntner Wirtschaftsförderungs Fonds KWF

The background of the page is a dark purple to black gradient, featuring a large, intricate spiral pattern of fine, concentric lines that create a sense of depth and movement. The spiral starts from the right side and winds inward, becoming more prominent as it moves towards the center.

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Institut für Vernetzte und Eingebettete Systeme
Alpen-Adria-Universität Klagenfurt
Lakeside Park B02
9020 Klagenfurt am Wörthersee
Austria | Europe
T + 43 463 2700-3640
nes.aau.at

Content

Employees of the institute

Editors

Christian Bettstetter and Kornelia Lienbacher

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JOHANNES HUBER

Professor at Universität Erlangen-Nürnberg, Germany

The foundation of NES back in 2007 has proved to be a good investment into Carinthia's future development.

All three professors performed an extraordinary start.

I have observed very remarkable achievements in both teaching and research for which several high-quality publications and awards give evidence. I am grateful for having had the chance to contribute to this success myself by way of guest lectures and a joint research project. May their future be equally successful!

MARTIN HAENGGI

Professor at University of Notre Dame, USA

The Klagenfurt group made an original contribution to wireless communications that greatly enhances our understanding of interference.

MUBARAK SHAH

Professor at University of Central Florida, USA

During my guest professorship at the Institute of Networked and Embedded Systems I not only enjoyed their hospitality but was also very impressed by the potential of this young and upcoming research group, in particular their efforts in technology transfer.