Hoping for lightning to strike

Researchers at the High Voltage Labs want to measure storm lightning. Their findings might optimise lightning protection.

Photo: Katrin Binner

Ready for action: Martin Hannig (l) and Volker Hinrichsen with lightning conductor and lightning meter.

By Uta Neubauer

From the window of his office, Volker Hinrichsen, Professor of Electrical Engineering, looks out onto one of the administration buildings for the city of Darmstadt. His attention goes particularly to the ten or so lightning rods on the roof. Lightning protection is necessary but often unsightly, says Hinrichsen, "Just ask any architect what they think about the rods on the building"

One alternative to conventional lightning protection, as invented by the American Benjamin Franklin in 1752, arrived on the market in the 1980s. According to the manufacturers, these systems protect a wider area and therefore require fewer rods. But, they have not been approved for lightning protection standards to this day, because they are contentious among specialists in the field. However, the established system inspired by Franklin does not offer ideal protection. "Time and again there are documented cases in which lightning fails to hit the lightning rod", Hinrichsen points out. Lightning also does not always hit the highest point on a building.

Before the lightning discharge occurs a positive surface charge develops on the ground and incepts a so-called positive connecting leader into the air. When the positive leader meets the head of the negative downward moving leader, both create a plasma channel for the primary discharge visible as light. The lightning strikes the point where the positive discharge originated. The new type of lightning protection systems exploits this mechanism by artificially improving the inception of a positive connecting leader to cause the discharge to occur earlier and therefore longer. It sounds plausible but has not yet been proven scientifically because real lightning is needed to conduct the tests. Real lightning is so rare and so powerful that it cannot be generated experimentally.

The TU Darmstadt has one of the largest university facilities for high voltage experimentation in Germany. "Even here we cannot imitate natural lightning", explains Martin Hannig, a postgraduate in Hinrichsen's work group. He now wants to take outdoor measurements to figure out how the positive connecting leaders are formed and how they influence the point of strike of the lightning discharge. These findings are expected to give answers to the fundamental question of how probable it is that lightning will strike a specific place. This would make it much easier to evaluate new types of lightning protection systems.

For the measurement of natural lightning, Hannig has developed a device ("lightning meter") with two signal pick-ups which register both the weak, high frequency pre-discharges as well as the more than 100,000 times stronger primary discharge. The first of 60 lightning meters have already been installed on the premises of the TU Darmstadt, while others are intended for places such as the lighting towers at the Frankfurt Airport. Hannig also refined a simulation model which calculates the probability of lightning striking based on data from buildings and properties. Using this model, he tests the suitability of potential places for measuring lightning, knowing full well that the chances of striking gold are overall slim. On average, there are two lightning strikes per square kilometre per year in Germany. The researchers in Darmstadt hope they can "catch" at least a few of them.

The author is a science journalist with a doctorate in chemistry.

Looking for places to take measurements
Martin Hannig is still looking for lightning rods, masts or other 20 to 30-metre free-standing structures where he can install his scientific lightning meters. The lightning meters have no influence on the probability of lightning striking. Locations in northern Germany are less suitable because there is a weaker concentration of lightning in that region. Interested parties are requested to contact him at: hannig@hst.tu-darmstadt.de

Information
High Voltage Labs
Prof. Dr.-Ing. Volker Hinrichsen
Im Carree 3, 64283 Darmstadt
Phone: 0049/6151/16-2529
E-Mail: hinrichsen@hst.tu-darmstadt.de

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Optimal use of flows

Humankind has been using water as a source of energy for millennia. The Institute for Fluid Systems at the TU Darmstadt under the direction of Professor Peter Pelz is researching how to generate the optimal yield from ocean currents.

History of the institute

The Institute for Fluid Systems Technology has been around for some time. Its origins go back to the founding of the Chair V of the Department for Mechanical Engineering V , figuring machines, hydraulics and plants under the direction of Professor Adolf Pfarr in 1897. During his time as director at the manufacturing firm Voith, he invented the first controlled hydroelectric turbine. The institute was renamed and reorganised when Professor Peter Pelz, formerly head of development at the Vibracoustic GmbH, was appointed to chair it in 2006. In 2011 Pelz published a pioneering tract on the maximum potential output for hydroelectric power plants in waterway flows. It formed the basis of all further projects on hydroelectric energy conducted by the expert with some of his doctoral students. The 28 scientists who make up the institute today work in five main areas of research: hydroelectric energy and fluid machines, technical operations research and techno-economics, tribology and rheology, cavitation, oscillations and acoustics.

By Jutta Witte

The water at Manuel Metzler's test station flows through a two-metre-long and precisely twenty-centimetre-wide flume where it meets a perforated sheet of iron ten centimetres wide. The engineer's physical model simulates the typical flow of running water facing a fence of turbines bypasses. The flumerepresents the channel and the sheet a so-called hydrokinetic machine, a turbine like one that might be used in a power station of the future using marine energy. The sheet "blocks" the current; this barrier drastically lowers the pressure whilethe current flows through the perforations in the sheet. At the same time, it accelerates the water and releases energy

"The exciting question is how much energy flows into the system and how much flows out the other end afterwards", explains the scientist at the Institute of Fluid Systems. "The difference between them lets us calculate how high our net yield is". As a postgraduate student on the team of Professor Peter Pelz, who directs the institute, Metzler has been researching the flow characteristics of flowing water for three years. His testing model enables him to simulate all possible water conditions—flowing, shooting or standing—and various scenarios. If, for example, he should enlarge the diameter of the simulated sheet iron turbine, the hydrokinetic energy will increase proportionately. If he should shift the resistance at the outlet of the canal to the right against the current, he will generate a "hydraulic jump". The wave thereby created triggers backwater, which lessens the energy yield.

The aim is to influence the current in such a way as to generate the maximum energy yield with the fluid system. Three factors are critical for determining this yield: the volume flow, that is, the amount of water which flows through a specific cross-section in a specific time, the drop height of the water behind the turbine and the degree of blockage. "In the tests we are mostly concerned with influencing the free surfaces, that is, the boundaries between the water and air behind the turbine", the 31-year-old scientist reports. Observing these boundaries is a new step. Until now, the effect of hydrokinetic machines has been calculated based on a law developed by the engineer Albert Betz in 1919 to determining the energy yield of windmills. It is the standard for calculating the efficiency of wind power plants and has been transferred to marine current turbines.

Betz said 59 per cent was the maximum possible yield one could generate from wind power during his period. "But this limit is obsolete for tidal power", Metzler points out. "We now know that we can achieve a maximum yield of fifty per cent if we include the free surfaces in the calculation". His experiments show that the efficiency of a turbine field increases proportionately to the ratio between the distance between turbines and the turbine diameter.

"Tidal energy is an an easily calculable factor."

Metzler also discovered that the water descent brings the primary flow to a standstill through a so-called secondary flow when it is blatantly too high but that the energy yield diminishes if it is too low. The tests confirm the analytical findings of the research group that the optimal ratio has been reached when the drop height of the machine is set at two fifths of the specific energy of the water when it begins the descent.

And yet, the research on flow characteristics is relevant to more than the fundamentals. The aim is to develop useful mathematical formulas with a finite number of variables to help the manufacturers of marine current turbines, emphasises Metzler. "Every planning engineer, operator and investor as well has to be able to understand them. We're consequently already taking future applications into account". So far, turbines for marine current power plants designed to function in the open sea without dams, unlike the tidal power plants already operating in France, Australia and South Korea, for example, only exist as prototypes at present. With a diameter of up to twenty metres, they look like

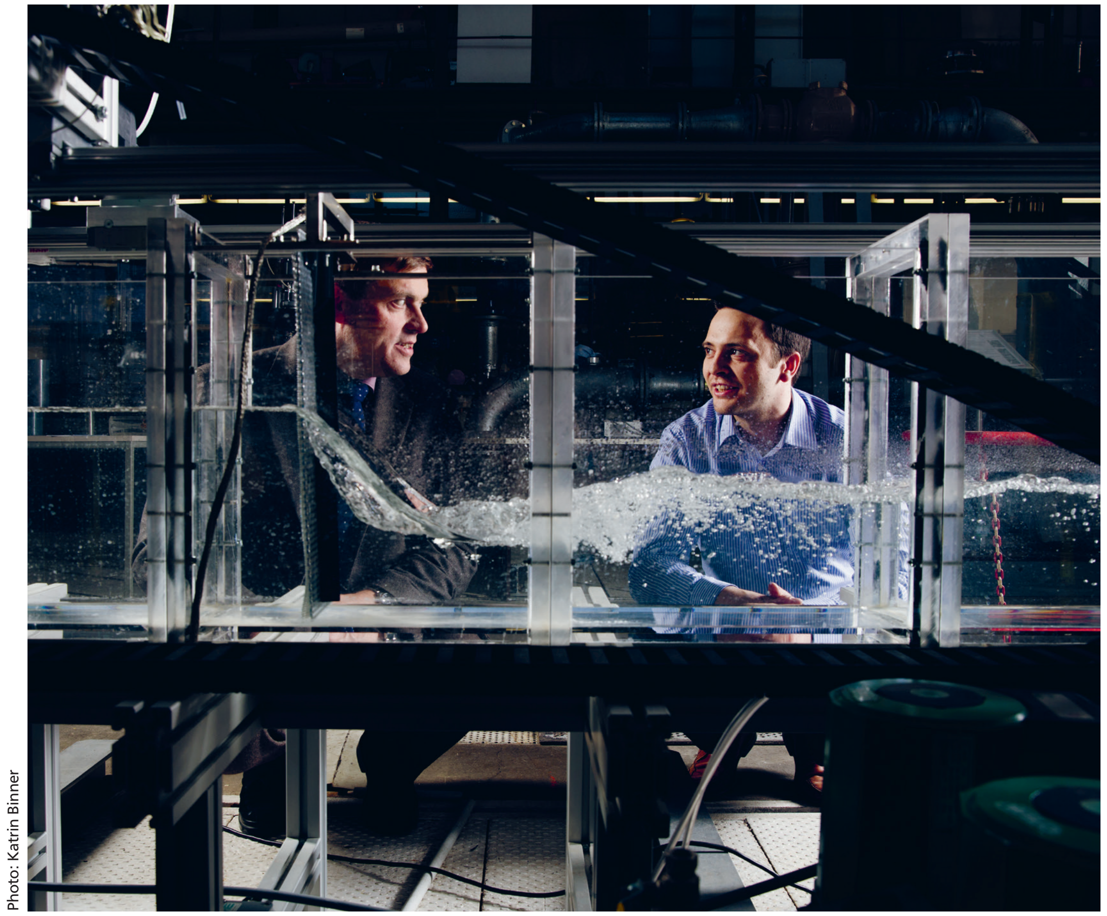

Photo: Katrin Binner

Manuel Metzler (r) and Professor Peter Pelz with their model of a tidal turbine.

wind turbines spinning vertically underwater. Even though this form of power plant is not likely to play a major role in the renewable energies mix here in Germany because of its geographical conditions, the experts at the Institute for Fluid Systems Technology foresee enormous potential abroad. "Tidal energy depends on the position of the moon to the earth. This makes it an easily calculable factor capable of bearing a constant load", Metzler explains. The scientist refers to research currently being done in this area, especially in England. The British see the area off the Scottish coast as a particularly high-potential region for deploying the new type of power plant.

With a view toward such innovations, the German industrial manufacturers are also showing interest and watching a future market emerge which might be worth investing in. Manufacturers are presently focused mostly on developing machinery which is robust enough to handle operation in the ocean. However, they are likely to raise the question of profitability soon. The scientists at the Institute for Fluid System Technology could give them some answers in this respect. In any case, Metzler is certain that marine current power plants will have a future where the topography allows them.

The author is a science journalist with a doctorate in history.

Areas of research

Fluid Machines is the name of one of the five areas of research at the Institute for Fluid Systems at the TU Darmstadt. Researchers in this area are occupied with hydroelectric turbines for one and develop new concepts for optimising and scaling environmentally sustainable hydropower. For another, they research scaling methods and methods for analysing energy efficiency. The doctoral thesis of Manuel Metzler entitled "Einfluss der freien Oberfläche auf die Leistungsausbeute von Wasserkraft bei geringer Fallhöhe" [Influence of free surfaces on the output of hydro power with low head] should be published in late 2015.

Interview with Professor Peter Pelz

What are the scientific challenges faced by fluid systems?

Optimisation is an issue here, as it is for all renewable energies. What is the maximum yield I can generate for how much cost? This is always the core question, even when we use the natural flows of tides or running water to generate electricity.

How do you approach this issue scientifically?

We operate under a specific research paradigm here in the institute. The focus is not on the machinery but on the overall system. For example, if a manufacturer making turbines for run-of-the-river power plants does not take the protection of aquatic life into planning consideration from the start, operators might not be able to run its turbines profitably. A holistic approach makes particular sense when looking at the use of renewable energies.

Which goals are you pursuing with your basic research in hydrokinetic turbines?

We're trying to give manufacturers something to orientate their development work. Our aim is to provide axiomatically proven and experimentally validated upper limits for potential energy yields and thereby ensure a degree of planning certainty. We use the system perspective to derive the optimal requirements for turbines with respect to yields. This gives us the technological and economic basis for manufacturers, planners, operators and investors.

Information

Institute for Fluid Systems
Prof. Dr.-Ing. Peter Pelz
Phone: 0049/6151/16-2153
E-Mail:
peter.pelz@fst.tu-darmstadt.de

Like a good butler

Jan Peters, Professor of Computer Science at the TU Darmstadt, teaches robots to play table tennis and hand materials as needed. His machines learn the way children do: through imitation and self-improvement.

Short history of the latest in robotics

- **1921** The Czech writer Karel Čapek coins the term "robot".
- **1954** The first industrial robot is patented.
- **1961** General Motors starts using robots for vehicle production.
- **1966** Shakey is the first mobile robot able of navigating.
- **1993** Honda develops the first walking humanoid robot.
- **1997** A robot lands on Mars.
- **2000** Robots are able to climb stairs.
- **2007** First helicopter robot wins the aerobatics competition through robotic learning.
- **2002** First commercially available robot vacuums floors.
- **2012** The first humanoid robot flies to the International Space Station.
- **2012** Google gets robots to drive cars.

Information

Intelligent Autonomous Systems
Department of Computer Science
Prof. Jan Peters, Ph.D.
Hochschulstr. 10, 64289 Darmstadt
Phone: 0049/6151/16-7351
E-Mail: mail@jan-peters.net
www.ausy.tu-darmstadt.de

By Hildegard Kaulen

How does a helpless infant become someone who strolls around and gets things done? Jan Peters tackles this question every day. The robotics expert and his staff aim at understanding how children learn motor skills and how they can teach a machine to do the same. Initially, newborns employ their reflexes and subsequently quickly learn to do everything their parents demonstrate to them. Children generalise rapidly and improve nearly all the time. Once they have learned to pour water from a bottle into a cup, they can also tip milk out of a carton into a glass. They have understood the principle of pouring and they will fill every glass, every cup, every mug unerringly so that not a drop goes astray. Peters, who also heads a research group at the Max Planck Institute for Intelligent Systems in Tübingen, intends to design machines that learn like children. Instead of putting a lot of effort into programming an unalterable control system, his approaches aim at enabling robots to find their own solutions. For the moment that means Peters is examining the foundations of the new field of robot skill learning. "The applications arise by themselves" the robotics expert explains as we talk. "At some point, a learning robot will be like a good butler or like a third hand attached to a human user. It should do what's expected of it while continuously improving its own skills".

> *"At some point a learning robot should do what's expected of it and constantly be improving".*

Peters' machines learn in a highly modular way that renders them more data efficient. The robotics expert develops algorithms for disassembling complex movements into movement primitives that can be learned by robots. Such movement primitives are collected in a movement database, which robots reassemble the original movements again or compose new, complex movements. The robots use machine learning algorithms that determine the probability of applicability for different movement primitives, which allows distinguishing effective solutions from less effective ones. To do so, they determine similarities between movements and compare their effects. When a robot is looking for solutions in its solution space, it will not necessarily find the same ones that the humans have shown the robot or which humans would use in a similar situation. Peters gives us an example. You want a robotic hand to pick up a glass. Its teacher shows it how to encircle the glass in its palm and hold it. Using its learning algorithms, the robotic hand comes up with a new movement sequence on its own in which it holds the glass using three robotic fingers pressed against the interior of the glass. This solution is unusual and tiring for humans. "We accept it because it serves the purpose, is a more robust solution for the robot to execute and does nothing to inhibit the actual goal", Peters says and reminds us that people are also constantly finding new solutions for movement sequences. Take olympic high jumping, for example. For a long time, athletes only jumped over the pole with their upper bodies upright or face down, until Dick Fosbury had the idea to jump over it face up in the 1960s. Nowadays, the Fosbury flop technique is the only one still used.

Peters joined the TU Darmstadt in 2011. He directs the Intelligent Autonomous Systems research group. The 38-year-old studied computer science, electrical engineering and mechanical engineering in Munich, Singapore and Los Angeles, earned four masters' degrees, received his doctorate in Los Angeles and worked in Munich, Japan, Singapore, Los Angeles and Tübingen. He is also interested in history and many other subjects. He is particularly fascinated with humanoid robots because it allows him to learn from other disciplines for ideas and new developments, such as neuroscience, cognitive science and sports science. Peters loathes being pinned to a single isolated aspect. He likes the freedom to regularly redetermine the focus of his research. "I want to choose the obstacles on my own way", he says, which is also the reason why he prefers to do his research at universities rather than companies.

Photo: Katrin Binner

Soon, the robot DarIAS will be able assembling furniture by itself. Professor Jan Peters just demonstrates the two-handed robot system the necessary movement primitives.

For a robot to learn on its own, it has to be capable of self-improvement. This ability is achieved through reward and punishment. Reward and punishment for a robot, however, are only numeric scores. The robot aims the expected numeric by changing its movements. This kind of machine learning is called reinforcement learning. The robot expands its solution space as needed. Peters gives us another example. Together with his team, he taught a robotic arm to play table tennis. The researchers witnessed that the robot would intially only play using its forehand but not its backhand. "We consulted with table tennis experts to learn about their movement patterns", Peters explains. "… but quickly learned that the movements were not the actual problem. Professional table tennis players don't look at the ball when they're playing, they look at their opponent. Thus, they can read their opponent's movements to determine where the ball will go. This intent prediction saves them the time needed to switch to their backhand". Peters and his colleagues consequently expanded the robot's solution space to include opponent observation. After a few training sessions, the robot was not only able to return 97 per cent of the balls fired from a ball launcher but it also became a serious opponent for its teachers. Based on these approaches, robots should be able to execute serious tasks and react to more complicated stimuli from their environment in future.

Do we need such learning machines? Factories without robots are no longer conceivable, Peters says. Few German manufacturer would be able to compete internationally without robots. However, industrial robots have to be reprogrammed for each new task. Such programming is costly. Hence, industry has a great need for self-learning machines. Peters also sees a need in private circles, such as households, caregiving and rehabilitation. "Given the changing family structures and the demographic shift, we won't have any other choice but to rely on the support of robots", he claims. Still, many problems still need to be solved before we reach that point. For example, compliant, light and backdrivable robots have to be developed. The solutions being used today are too rigid and cannot easily be stopped if they hit an obstacle at high speed, which could be life-threatening in the home environment. To obtain safer robots, we need to develop more intelligent machine learning for control methods. "Such methods might ready faster sooner than we think", Peters says. "Sometimes difficult problems are solved overnight through machine learning".

The author is a science journalist with a doctorate in biology.

No queues on the web

The internet and its applications and expanding exponentially. Teams at the MAKI collaborative research centre of the TU Darmstadt are developing dynamic mechanisms of communication to maintain the web's enormous performance capability.

By Jutta Witte

Every internet user knows the situation. Just when you find your favourite TV show on YouTube and press play, the video quivers and hangs because the network is overloaded. Or even worse, the deciding goal in the final game of the World Football Cup reaches your TV streamer later than your neighbours' due to so-called latencies, that is, delays in transmitting the game. More and more data, users, apps, end devices, new forms of communication like hashtags and flashmobs and augmented reality games like Ingress are pushing the internet to the borders of its capacity and sometimes bringing it to a standstill.

"Nowadays the internet has become a driving force for our society and it will continue to cause serious upheavals", Professor Ralf Steinmetz director of the German Research Foundation's collaborative research centre MAKI – Multi-Mechanism Adaptation for the Future Internet – predicts. "Network technologies have to adjust to this trend and ensure that data transmission quality remains reliable". Steinmetz and his team are convinced that completely redesigning the Internet is not the solution. The problems of switching to the new IPv6 internet protocol alone demonstrated how difficult such reforms are, project colleague Björn Richerhagen explains. "The fundamental idea of shutting down the Internet, rebuilding it and putting it back into operation on the next day is unrealistic".

"Network technologies have to adjust to this trend of radical change and ensure that data transmission quality remains reliable".

Instead, scientists are focussing on the transition principle, that is, the smooth, dynamic replacement of complete communications mechanisms across shifts during operation. "This would allow us to use the multitude of services along with their related standards flexibly and effectively," Steinmetz believes. How this might look can be seen on the MAKI Demonstrator, where project colleague Stefan Wilk is simulating a video streaming scenario. A central computer transmits a live video and one by one the users of six mobile end devices try to stream the film. However, only the first two succeed. The other four wait in the queue. Wilk presses the MAKI button. Now the system recognises the overload situation and decides to switch from the central mechanism to peer-to-peer transmission in order to relieve the load on the server. The two end devices which are already receiving the video step in and transmit the film onward via their WLAN connection.

"Functions accomplished by networks are more and more shifted towards the users and away from the major providers", Richerzhagen reports. This trend might not only be the solution for video streaming but also apply to managing the enormous volume of data which the community likes to share about big events these days. For example, the organisers of the Oktoberfest in Munich have now started setting up additional receivers to handle sudden peaks in transmission. The experts at MAKI think it would be more cost effective and expedient if smartphones could switch to other wireless technologies like WLAN, Bluetooth and near field communication in emergencies. In that case, as the described lab tests demonstrate, the "Wiesn" in Munich would see peer-to-peer connections set up or information would be shared in snowball fashion through something like spontaneous, ad hoc networks.

Information

Collaborative Research Centre (Sonderforschungsbereich) 1053
Prof. Dr.-Ing. Ralf Steinmetz (Head)
Rundeturmstr. 10
64283 Darmstadt
Phone: 0049/6151/16-6010
E-Mail: sprecher@maki.tu-darmstadt.de
www.maki.tu-darmstadt.de

Photo: Katrin Binner

Experimenting to find the communication systems of the future: Björn Richerzhagen, Ralf Steinmetz and Boris Koldehofe (l to r)

"This would save resources, take the load off of the supporting infrastructure and improve transmission quality", Richerzhagen says. As part of the "Information-centric View" MAKI sub-project, the electrical engineer is currently researching the most efficient ways to distribute information which should go to various users and be updated frequently. The publish/subscribe communication paradigm might be the answer. It severs the direct link between publisher and consumer, but it uses broker networks and peer-to-peer systems to ensure that messages are delivered to the right parties. In this case, the receivers "subscribe" to the information according to their own search criteria and receive a message when this information is available. The sender and receiver do not even have to know who the other is. This creates a flexible communication system which might be used, for example, for augmented reality games like Ingress. The strategy game which is currently booming in the community connects real places to the virtual gaming world and demands mobility and speed. Two competing factions battle for a territory and attempt to secure it for themselves by virtually conquering strategically important places like the Eiffel Tower or the Brandenburg Gate. There are bottlenecks in the network because players usually spontaneously gather at the contested (real) sights to carry out their battles right on site.

The planned system might relieve some of the burden. The gamers would still locate each other using their mobile network but on site they would automatically and seamlessly switch to Bluetooth or WLAN once they were in reach of each other. For this to work, each end device would have to be registered with MAKI. The system would then decide on its own which mechanism to use when and it would announce this decision using publish/subscribe. This kind of scenario is one of the long-term goals of the underlying project. The main task of the scientists at present is to use concrete application cases to observe already existent mechanisms and from their findings to develop building blocks for potential transitions and models for these to work together. "In the long term, we want to develop a methodology that would allow us not only to react automatically to changes in the surrounding conditions but to adjust the communication systems to these conditions proactively", MAKI director Steinmetz explains. In the opinion of the experts, this would both change how global network operate in the long term and support restructuring it technologically.

The author is a science journalist with a doctorate in history.

Publications

on the topic of video streaming:
Wilk, S., Rückert, J., Stohr, D., Richerzhagen, B., & Effelsberg, W.: Efficient Video Streaming through Seamless Transitions Between Unicast and Broadcast (Demo). International Conference on Networked Systems (NetSys 2015). IEEE.

Facts and figures

MAKI stands for the collaborative research centre 1053 "Multi-Mechanism Adaptation for the Future Internet" of the German Research Foundation (DFG). It was launched in January 2013 with initial funding of eight million euro over four years. Under the direction of Prof. Dr.-Ing. Ralf Steinmetz, around 50 scientists, 22 of whom are postgraduates, research new construction methods, models and procedures for the communication systems of the future. It is divided into the three interconnected project areas of Construction Methods, Adaptation Mechanisms and Communication Mechanisms. The faculties collaborating in MAKI span multiple universities, including the Department of Electrical Engineering and Information Technology, the Department of Computer Science and the Department of Social Science and History at the TU Darmstadt, the Department of Computer Science at the RWTH Aachen and the Department of Computer Science at the University of Illinois.