

Nanotechnology for Wireless Communications

Devices using wireless communication range from TV receivers to RFID tags, and mobile phones to satellites. Internet access from mobile phones and tablets is growing exponentially, which puts increasing demands on the performance of mobile devices and networks. Radio frequency (RF) electronic components use a lot of passive components, like capacitors and inductors, which cannot be miniaturized as fast as transistors and digital electronics circuits¹. It is foreseen that within the next 10-15 years the current RF technologies will not be able to meet the ever increasing performance requirements of mobile handsets. Wireless sensors for health and sports monitoring have already become commonplace, and wireless connections are used extensively between household devices, in security systems and in monitoring and logistics systems in factories and warehouses. The development of smaller, cheaper, less power consuming and more efficient wireless sensor devices is expected to have considerable impact on these areas and enable new solutions for services, healthcare, environment monitoring, and logistics.

How can nano help?

The main drivers for using nanotechnology in wireless devices are:

- Increased use of RF spectrum;
- Slower performance improvement of RF components compared to digital electronics; and
- Demand for cheaper, smaller and less power consuming devices.

Tuneable radio components

It has been estimated that by 2015 the amount of data transferred via wireless connections will be greater than the data transferred via wired connections in the US². The Digital Agenda for Europe has set a target of providing 30M bps access to all European citizens by 2020. This is a challenging target, since the radio frequency spectrum is a limited natural resource, which needs to be shared by multiple different radio systems. Already, many of the frequency bands are becoming crowded, which hinders and slows down the data traffic. New spectrum sharing methods and protocols are being designed to alleviate the problem.

To cope with the multitude of different operation frequencies mobile devices currently incorporate several different radio transceivers. A more flexible solution under development is to do the baseband

and radio frequency (RF) processing with software and generic multiradio RF components. However, the electronics required for radio front ends is specific to the used frequency and can't be tuned to all the required frequencies with current technologies. New, more *tuneable radio front end components* are required³. Graphene nanoelectromechanical (NEMS) resonators have been proposed as tuneable resonators. Graphene strip can withstand very high strains, which makes it possible to tune the operating frequency of the resonator over a wide bandwidth by straining it electrically.

High frequency electronics

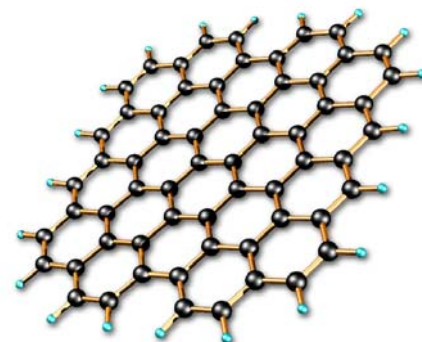
In addition to new spectrum sharing methods, the experts foresee that soon additional frequency bands are also needed. There are already ongoing standardization efforts to introduce new frequencies for mobile data traffic in the higher frequencies, around 2-5 GHz and up to 60GHz. The need for more spectrum does not stop here, but devices operating at 60-100GHz frequencies will be needed in the future. These are out of the limits of current silicon-based transistor technologies. New solutions are needed for electronics capable of operating at very high frequencies. Promising alternatives are RF-transistors made of graphene.

Graphene electronics

Graphene is a two-dimensional lattice of carbon atoms, with exceptional electrical, optical, thermal, chemical and mechanical properties. Since its isolation in 2004, several applications have been demonstrated:

- Graphene transistors with operating frequencies over 100GHz
- Radio frequency mixers and other components
- Flexible graphene touch screens and circuits
- Very fast optical sensors and ultrasensitive chemical sensors
- Electrode materials for supercapacitors

The main obstacles for commercialization are in manufacturing of good quality graphene films and integrations with silicon technologies.



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Wireless sensors

The trend towards intelligent environment and ubiquitous information access means that new types of autonomous sensors with wireless communication links will be embedded in everyday objects. The devices must be small, cheap and capable of operating with power supplied by a very small battery, or electricity harvested from light, radio waves or thermal energy. New nano-enabled sensors combined with miniaturized RF transceivers can be used for health monitoring devices, and monitoring of air quality, soil or water pollution.

RFID tags are very simple, usually passive devices, which can be read using a radio frequency transceiver. Fabrication by printing can reduce the costs of wireless sensors costs substantially, and nanoparticle inks can be used to increase the performance of the printed devices⁴.

Thermal management

Thermal management is a problem which is specific to mobile devices. The heat generated by the electronics has to be dissipated, and when the devices are getting smaller and power densities higher this gets more and more difficult. Thermal management is a severe limitation already today, and will become critical when the even more complicated as the software applications and high speed data traffic demand more powerful proces-

sors, and at the same time the circuits get smaller. It has been estimated that in 10-15 years time the conventional electronics and foreseen thermal management methods can't remove the generated heat from a small handheld device fast enough to keep the surface temperatures comfortable³. Nanomaterials like carbon nanotubes have been studied as on-chip cooling elements due to their excellent heat conduction properties.

Impacts

Radio frequency technologies make possible sectors such as the telecommunications industry, which is one of the fastest growing industry sectors worldwide. RF technologies are therefore very important from the economic perspective and also from regulatory, health & environmental and national security perspectives. The development of these technologies have a crucial role in the everyday life of the general public and in the modern European economy.

Economic/Industry (WP3)

The economic impacts of radio frequency technologies (RF) are significant. The global market for products utilizing digital radio, high-definition TV, advanced cellular, wireless networking, RF identification, global positioning systems and radio frequency plasma was worth nearly **€149 billion**

Components of a wireless device		Examples of nanotechnology enablers
Radio transceivers	Antenna	Nanomaterials for low loss antenna cavities, nanoparticle inks for printable antennae, carbon nanotube antennae for in-chip connections
	Analogue signal processing	Graphene-based high-frequency RF circuits, printable electronics, spintronics, plasmonics
	RF front end circuits	Graphene NEMS resonators
	Digital baseband processing	Photonics, spintronics, nanowire transistors, nanoparticle inks for printed electronic circuits
Power	Energy harvesting	NEMS systems, thermoelectric materials
	Storage	nanomaterials for supercapacitors of fuel cells
Sensors	Optical	Organic photovoltaics, quantum dots, nanophotonics, plasmonics
	Chemical	Nanowires/nanotubes, nano-arrays...
	Mechanical	Nano-electromechanical devices (NEMS)
	Electrical/electrochemical	Nanowire/nanotube transistors, ion-selective field effect transistors...
Memory		New materials for ferroelectric RAMs, CNT memory, phase change memory, molecular memories...
Output/feedback devices	Display/light	LEDs, quantum dots
	Mechanical actuators	Ionic electro-chemo-mechanical actuators (CNTs, vanadium oxide nanofibers)
Thermal management		Nanomaterials with enhanced thermal properties, carbon nanotubes, graphene electronics

Table 1: Examples of nanotechnology enablers for wireless devices

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in 2010 and is expected to reach €309 billion by 2015⁵. The total global market estimations for mobile phones, RFIDs, antennae and Microsensors are presented in Figure 1.

Technology readiness levels

The current RF technologies have limitations which can't be easily or cost-efficiently overcome, and nanotechnological solutions are seen by the experts as a promising alternative. However, most of the technologies are still in research phase, and a lot of research and engineering is needed before these would be ready for commercial use. In particular, significant efforts are needed to get from the component-level research to the system-level solutions.

RFID tags fabricated with printed electronics are already available, and new nanoparticle inks are close to commercialization.

Societal/Impact on European Citizen

Mobile devices are already part of the everyday lives of most Europeans. The total impact of economy is difficult to assess, since mobile internet access has affected almost all the areas of our society in some way. It has enabled new kinds of services and created new jobs in the IT and service sectors.

Nano-enabled wireless sensors can have a big effect on healthcare. Already, wireless devices are used extensively e.g. for data transfer from wearable monitors or sensors like blood pressure or blood sugar sensors. Nanotechnological developments can make wireless sensors cheaper, smaller, more energy efficient and have better compliance with biological systems. Low-cost health monitoring devices, for example manufactured by printing,

would make them accessible to larger population and increase their use in public healthcare. The nanotechnological developments for sensors and electronics will also enable totally new methods for in-body monitoring, minimally invasive diagnostic systems and controlled drug delivery.

Cheap and possibly biodegradable wireless sensors and sensor networks could be used for **environmental monitoring**, for example to get more accurate data for weather forecasts and climate monitoring, or for more comprehensive monitoring of water and soil quality.

As RFID technologies become more widely adopted, it is likely that there will be some reduction in the number of employees required in warehouses and distribution centres. However, there will be an increase in jobs involving researching, creating, installing and maintaining RFID systems, and also in jobs for those who design, manufacture and sell products utilizing RFID.

Challenges

- Key drivers for using nanotechnology in wireless communications come from improved performance, smaller power consumption, smaller size and new features such as flexibility or transparency. Some of these are already proven to be technologically feasible, but many **technological difficulties** are still unsolved.
- **Cost reduction** is an important driver: new technologies will not gain market share until they become cost competitive with existing solutions. The barriers of commercialisation of new technologies for RF electronics are less severe than in digital electronics, since there is a clear need for replacement technologies.

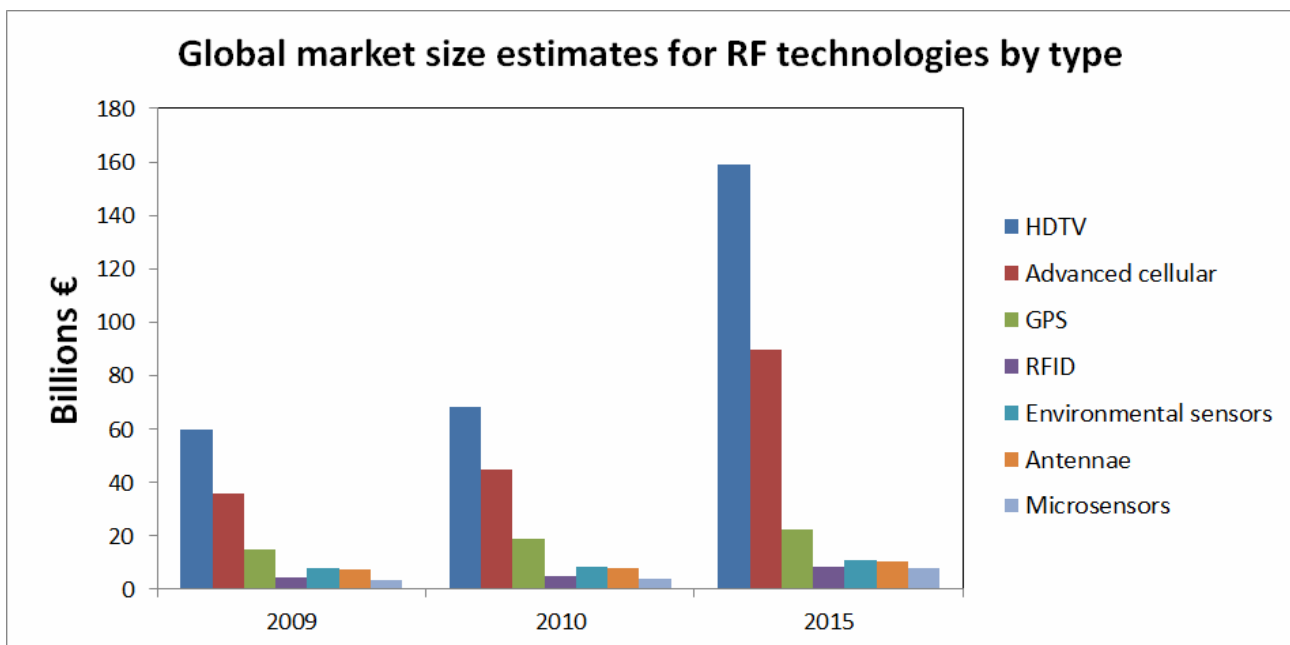


Figure 1: Global market size estimates for RF technologies by type⁵

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Figure 2: A concept for nanotechnology-enabled mobile phone, the Nokia Morph. Reproduced with permission from ³.

- Based on expert feedback, the economic barriers have a moderate to major impact, technological and policy barriers have a moderate impact, and the environmental, health and safety barriers and society barriers are expected to have some impact.
- The environment, health and safety effects of nanomaterials in wireless communication devices are expected to be similar to those of other electronic circuits. Candidate nanoparticles for wireless communication are generally substrate-bound or incorporated into a host matrix and fully packaged to circuits. Users are therefore not expected to be exposed to nanomaterials during normal use of the devices⁶. Nevertheless, the development of autonomous wireless sensors requires a careful assessment of the human and environmental impacts, particularly if the sensors are designed to be in contact with the body or implanted (e.g. for physiologic/metabolism monitoring) or disposable (e.g. for environment monitoring).
- The social aspects of ubiquitous information access and ambient intelligence systems have not been sufficiently researched yet. In particular, questions about privacy and security need to be carefully assessed⁷.

EU Competitive Position

Traditionally, Europe has been strong in the mobile phones sector, but during the last couple of years Asian and American competitors have been increasing their market share. In terms of patents on wireless technologies and standards, the position of Europe is still relatively strong.

The European market of RFID technologies is estimated at 20% of the global market, and its share is growing⁸. European actors have a strong position in the RFID value chain and Europe is a major competitor in the global RFID market.

EU's patenting position is stronger in the RFID application field but it is lagging behind the US in core standards related to RFID technology.

Summary

- The use of wireless communication systems is increasing very rapidly
- Key drivers for using nanotechnology in wireless communications are improved performance, smaller power consumption, smaller size and new features.
- Current RF technologies for high data rate communication systems are expected to be capable of meeting the industry needs for the next 10-15 years, but after that fundamental physical limits of the radio electronics will start to hinder the development. New solutions are needed, but they are still in the research phase.
- Wireless sensors and sensor networks have applications in logistics, security systems, and health and environment monitoring,
- The main societal concerns for ubiquitous information access and sensors networks arise from security and privacy issues, as well as environmental aspects for disposable sensors.
- EU has a strong position in the mobile device and RFID value chain, and in many segments European actors are among the market leaders

Further information

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