Guardian Angels for a Smarter Life

1 Billion Euros for Zero Power

Adrian M. Ionescu
Outline

• **Introduction:**
  – the IT Platform of Today: at the edge of the cloud

• **Guardian Angels for a Smarter life:**
  – concept: enabled by Zero-Power
  – the next electronic switch
  – role of heteroingenous integration:
    • Novel architectures and materials (silicon, carbon, III-V)
  – bridging research and communities
  – enabling a revolution in academic curricula

• **Conclusion**

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Innovation semantic waves

Guardian Angels

Industrial Revolution

Rapid Adoption

1771

1800

1853

1913

1969

2025

2061

2081

Textile

1825

1853

1913

1969

2025

2061

2081

Railway

1886

1939

1997

2007

2025

2061

2081

Auto

Computer

Distributed intelligence

Nanotech

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1. Today: **Mobiles at the Edge of the Cloud**

2. Today: **The unfulfilled promise of Wireless Sensor Nets**

Source: Jan Rabaey 2008.
**WSN: the birth of the Swarm**

**Challenges:**
- economy of scale
- interoperability
- energy
- reliability
- cost & easy to use

Interconnected smart objects enabled by energy efficient nanotechnology: the Guardian Angels.

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Guardian Angels are future zero-power smart autonomous systems featuring sensing, computation and communication beyond human aptitudes. They can harvest different kinds of energy.
Enabled by zero-power

○ **Zero-power is the system ability to harvest energy** existing in dynamic environments (solar, thermal, vibration, electromagnetic) and power-up the smart GA systems.

○ **GA’s are smart personal companions**
  - They will actively assist humans from infancy to old age in any life situation.
  - They are autonomous, straightforward and non-intrusive.
  - They are smart, controllable, secured and personalized.

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Energy limits drive the zero power technology platform.

3 generations of Guardian Angels

- Zero-power system design
- Energy harvesting, storage & green batteries
- Energy efficient technologies

Multi-modal:
- Intercommunication, Scavengers
  - Non-invasive & invasive
    - + ultra low power computation & communication
    - + graphene based RF front-end
    - + ultra low power memories
    - + integrated nanosensor arrays
    - + disruptive harvesting

- Emotional
- Physical

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• Heterogeneous integration at affordable cost
• Drivers: power consumption and novel functionality

Guardian Angels zero power platform

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Power challenge

- Power per chip continues increasing.
- Leakage power dominates in advanced technology nodes.
- \( V_T \) scaling saturated by 60mV/dec physical limit.
- Voltage scaling slowed: 45nm=1V, 22nm=0.8V

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Reducing threshold voltage by 60mV increases the leakage current (power) by ~10 times.

Performance metrics: $I_{ON}$, $I_{ON}/I_{OFF}$, $S$, $V_T$, $V_{dd}$, $\tau$

$V_{dd} - V_T \approx \frac{V_T}{kT/q}$

Source: Intel Corporation

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Conduction band profile in transport direction in a long channel MOSFET.

• The gate voltage moves the conduction band downwards, so that a larger fraction of the exponential tail of the source Fermi distribution can contribute to the current.
• This gives rise to the exponential increase of the current.
Energy limits and swing

\[
E_{\text{total}} = E_{\text{dynamic}} + E_{\text{leakage}} = \alpha L_d CV_{dd}^2 + L_d I_{\text{off}} V_{dd} \tau_{\text{delay}} \approx \alpha L_d CV_{dd}^2 + L_d CV_{dd} \frac{I_{\text{off}}}{I_{\text{on}}} = L_d CV_{dd}^2 (\alpha + \frac{I_{\text{off}}}{I_{\text{on}}}) \approx L_d CV_{dd}^2 (\alpha + 10^{-V_{dd}/S})
\]

\[
P = \alpha L_D CV_{dd}^2 f + I_{\text{off}} V_{dd} \approx KCV_{dd}^3 + I_{\text{off}} V_{dd}
\]

A technology that would enable a voltage scaling by a factor of 5 (from 1 V to 0.2 V) with a negligible leakage power (with ultra-low \( I_{\text{off}} \) due to a small \( S \), as the TFET) could offer a power dissipation reduction of 125x.
Lower CMOS fundamental limit in energy per operation by subthermal S novel devices

Parallelism (multi-core) is a key technique to improve system performance under a power budget


Source: T.J. King, UC Berkeley.
The next electronic switch

- **Improving the MOSFET switch:** *evolutive, additive technology boosters.*
  - Channel engineering to reduce the $V_{dd} - V_t$ (Ge, III-V, graphene, etc).
  - Nanowire and nanotube FETs for improved electrostatic (subthreshold leakage) control.
- **Reduce the $V_T$ and $V_{dd}$ by a novel small swing switch.**
Tunnel FET vs. future FET

Tunnel FET is the most promising small swing switch for $V_{dd}$ scaling.

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Quantum mechanical BTBT at the rescue

\[ I_{BTB} \propto T_{WKB} \approx \exp \left( -\frac{4\lambda\sqrt{2m^*E_g^{1.5}}}{3\hbar(\Delta\Phi + E_g)} \right) \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Means of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m^* )</td>
<td>Small effective tunnel mass, SiGe, III-V, CNT</td>
</tr>
<tr>
<td>( E_g )</td>
<td>Source in SiGe, III-V heterostructures, strain CNT</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>3D geometry (wrap gate), high-k gate dielectric, thin gate dielectric</td>
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Integration of a Field Effect Transistor (FET) into the suspended body of a silicon nanowire or carbon nanotube resonator results in integrated sensors with mass-sensitivity below $10^{-19}$ grams and power consumption in the order of nW.
Energy harvesting systems

- Solar Energy
- Thermal Energy
- Vibration Energy
- RF Energy

Source: Ch. Hierold, ETHZ.

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Strategy for energy harvesting

The application of energy harvesters is driven by system requirements:

- **Energy efficiency** by recovery of dissipated energy, and renewable energy
  - solar energy, automotive and industrial systems
- **Autonomy to avoid battery replacement** and infrastructure costs
  - industrial automation, sensor networks for environmental monitoring and structural health, building automation
- **Autonomy for convenience** in wearable electronic devices
  - sport, health / home care, life style, short range communication

There is no winning concept:
The analysis of the system specification defines the right type of harvester or combination of harvesters
Disruptive harvesting ideas

Bio-inspired energy scavenging: artificial photosynthesis

- Environmentally friendly materials
- High efficiency indoor & outdoor
- Low cost processing

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Emotional interfaces

Tomorrow: comfortable, accurate, continuous emotion monitoring in real life situation

- Wearable and disappearing systems for real-time measurement of stress and emotion
- Multi-modal for improved accuracy: combine ANS, cognitive and bio-chemical information
  - ANS for physiological arousal
  - EEG for cognitive valence of emotion (positive – left hemisphere, negative – right hemisphere)
  - EMG of the trapezius muscle
  - Voice analysis
  - Chemical monitoring of sweat incl Cortisol
- Ultra-low-power for miniaturization and long term use (> 1 month) => zero energy: ultra low power, energy scavenging, micro batteries
- Smart, private and connected

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Impact

- **Society and life**
  - as personal companions, GA’s will preserve human health and improve the quality of life for all categories of ages, in an affordable way
  - GA’s will make our environment more interconnected and smart, more energy efficient and safe
  - Disruptive technology focused on prevention based on augmented information for personal level decision

- **Leadership in science and technology**
  - leading role of Europe in zero-power novel technologies
  - enabling a stronger role of manufacturing in Europe
  - improving the competitiveness for leading communication and medical companies

- **Employment**
  - creation of new employment in Europe in ICT domain
  - new business opportunities
Pharmaco-therapy
- early detection of treatment inefficiency or relapses.

Prevention/diagnostic
- early signature of disease, metabolic and cardiac disorders.

Early detection of abnormalities by a Guardian Angel

Continuous monitoring
- Homeostasis
  - Hormonal
  - Metabolic
- Compliance to treatments
- Biomarkers
  - Cancer
  - Infectious diseases
- Physical parameters
  - Activity
  - Circadian rhythm
  - ECG, EEG

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Initiatives for improving the energy inefficiency of complex systems:

- IBM’s Smarter Planet
- Intel’s Green initiative

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Research projects vie for EU’s €1bn funding prizes

May 4th, 2011

‘Grand challenge’ finalists selected

Two to be chosen from shortlist of six
By Clive Cookson in Budapest

Europe has shortlisted six “grand challenges” as flagship research initiatives, including developing robots as personal companions and building a supercomputer simulation of the human brain.

Two winning projects will each receive €1bn (€1.5bn) in funding over 10 years.

Nerel Kros, European Commission vice-president, announced the finalists on Wednesday at the Future and Emerging Technologies conference in Budapest. The aim was to produce “successes that will be remembered, not just for today, but for a lifetime,” she said.

The contenders will each receive €15m from the Commission’s Future and Emerging Technologies programme to work up their proposals before winners are chosen late next year.

The projects are expected to involve large networks of university and industry researchers across Europe and beyond.

“With the flagships it is not just about the excellence of the science,” said Roberto Moreschi, Europe’s director-general for information society and media.

“Will it be possible on scientific grounds to tell the six projects apart in a year’s time? I think not. The winners will have to be determined by non-scientific priorities.”

Although Switzerland is not a member of the European Union, it is a full participant in EU research programmes and two of the shortlisted projects are led by the École Polytechnique Fédérale de Lausanne.

Perhaps the most futuristic is EPFL’s Guardian Angels, which will use computing and imaginative energy research to “create the ultimate smart device that will assist humans from infancy to old age.”

The Guardian Angels will “scarce energy,” for example by tapping the heat and movements of the human body.

Two projects concentrate on finding new ways to process vast amounts of data that are impenetrable using today’s computers.

The most widely-ranging is the FutureICT Knowledge Accelerator, which would create a computer simulation of the whole planet, encompassing everything from climate to population movements and the economic system. Within this there would be several “crisis observatories” running “big data” mining operations to warn of impending disasters such as financial crashes, emerging epidemics and environmental instabilities.

The other data-intensive project will apply IT to medicine to find better ways to apply all the health information gathered from the Human Genome Project and various biobanking projects to individual patients.

Perhaps the most futuristic is Guardian Angels which will use computing and imaginative energy research to create the ultimate smart device that will assist humans from infancy to old age.
GA’s movie