# METRICS AND MEASUREMENT TECHNOLOGIES FOR GREEN COMMUNICATIONS

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## CRITICAL NATIONAL NEED FOR GREEN COMMUNICATIONS

This whitepaper proposes a critical national need to scientifically define and develop metrics and measurement technologies for realizing Green Communications.

*Magnitude of the Problem*

Information and communications technology usage has grown at an almost exponential rate worldwide with an estimated 6 billion users in 2007 [1]. With the introduction of the iPhone and other software driven smart phones the Internet is now accessible from a mobile platform which will place even greater demand for broadband. By 2015 the downlink traffic from cellular handsets is expected to grow more than eight fold rising from 56MB per month to 455MB [2]. Addressing the issue of greener communications has significant broader impacts beyond just the United States as the developing world will account for more than 75% of the cellular users by 2015. Every year, 120,000 new base stations are deployed servicing 400 million new mobile subscribers around the world [3]. Remote regions will rely on inefficient fuel sources, such as diesel generators, that will significantly grow the carbon footprint of telecommunications even more.

Cellular operators have focused technological developments primarily on meeting the demands of the consumer for increased broadband. However, the recent dramatic increase in energy costs and greater awareness of their impact on the environment is shedding new urgency on improving power efficiency in communications. Placing the energy usage of cellular networks in perspective, each base station antenna and its supporting equipment consumes an average power of 1 Kilowatt, using a total of 8,800 Kilowatt-hours each year, which is equivalent to the energy used to run two typical 3 bedroom family houses in the UK, or one average household in the USA [4]. A medium sized network constituting 12-15,000 cell sites, each equipped with 2 technologies (2G & 3G) and around 3 antennas per technology, accounts to an energy use of 736,000 Megawatt-hours which is equivalent to running 168,000 European family homes [4].

In some telecommunications markets, energy costs account for as much as half of a mobile operator's operating expenses [5, 6] while over 1% of the entire world's carbon footprint is due to telecommunications [2]. Combining the growth in demand with the ever increasing cost of energy, and the related environmental fallout creates societal challenge than will negatively affect society in the United States and across the world if not addressed.

*Societal Challenges*

The ubiquity of communications technology is inextricably tied to the use of the Internet which is experiencing a societal integration that the Energy Information Administration has stated will grow annual energy consumption dramatically [7]. Increasing cell phone usage and mobile broadband downloads will create a cascade affect requiring more powerful base stations and in turn higher capacity backhaul requirements from fiber optic and microwave links. The societal momentum behind information and communications technology is too great to expect a slowdown.

The current status quo for designing communications systems inherits the layered architecture of the OSI model with distinct separation between layers. While this model has enabled dramatic technological innovations, it also creates a roadblock to transformational improvements. A new design paradigm is required that holistically integrates the entire communications network from the physical layer through global networking systems.

## RESEARCH OVERVIEW

The very term 'Green Communications' lacks clear scientifically based definitions and quantifiable metrics. Currently, it is more of a marketing term than a standard to strive for.

The critical nation need for a programmatic focus on Green Communications encompasses cross discipline aspects of communications, networking and alternative energy. A cursory viewpoint might only consider efficient power amplifiers or the use of alternative energy sources for cellular base stations. The reality is that to truly address this problem on a transformational level, high-risk high-reward research is required that integrates all aspects of communications stack and peripheral interactions. Most importantly, metrics and their associated measurement science that define green communications from combined energy efficiency and network optimization perspectives must be developed. Metrics are essential to providing guidance to manufacturers and service providers to help them make better decisions regarding infrastructure development and purchases. This requirement maps directly to the core competencies of NIST.

The study of green communications will require investigation in several areas such as power efficient RF hardware, efficient MAC protocols, networking, and integration of renewable energy with communications equipment, frequency reuse deployment strategies, and spectrum policy. While each area individually contributes to energy consumption, researching the interaction across separate layers will provide the truly transformational discoveries. For example, the status quo for design methodology separates the PHY layer from the MAC layer. Silicon RF designers do not interact with MAC layer software protocol development. This disconnect realized from the vertical architecture we have come to rely upon is a barrier that must be overcome.

Recent advances in the area of cognitive radio [8] have significant potential towards green communications. Cognitive radio devices sense their environment, adapt to different conditions, and incorporate long term learning. Integrating situational awareness of the wireless spectrum, power grid usage, and the needs of the systems users with the power control of base station devices opens up a new world of cognitive power control [9]. Energy output can be scaled in relation to the traffic needs and within the context of the power usage within the entire electrical

grid. For example, controlling the power output of energy consuming devices can help balance the load with the supply, while controlling the power of energy producing devices can balance the overall performance of the grid. Currently, in mobile communications a power consumption reduction at the base station may require a power increase at the handset resulting in a net loss. A non-traditional, interdisciplinary strategy that emphasizes a cross layer approach is needed to avoid component level interactions that at one level show improvements but in reality result in net zero gain or net loss.

The pathway to green communications will lead to further transformational breakthroughs such as power efficient distributed computing. The ubiquity of wireless communications combined with improved processer capabilities of devices, such as smart phones, will enable a new paradigm in networking design.

A programmatic effort in green communications will engage participation from a broad cross section of entities including the US wireless industry, government agencies and national laboratories, component manufacturers, product developers, and universities. Representation from all layers of the protocol stack from the PHY layer, through application level must be involved to truly create a new paradigm shift that changes breaks the current status quo of design. We believe that this engagement will help US manufacturers stay competitive by creating products that are more appealing to the developing world where energy costs and availability are an ever greater concern. Finally, this research endeavor would integrate participants from across a variety of communications fields including networking, telecommunications ranging from cellular to Wi-Fi to WiMAX, fiber optics, power technologies, and alternative energy providers.

## TRANSFORMATIONAL RESULTS

The potential outcome of an interdisciplinary and cross layer strategy creating Green Communications has the power to enable disruptive changes to the current limitations created by vertically separated layered design. This high-risk/high-reward research has the potential to breaking through this entrenched design process. The results will have wide ranging implications beyond just communications affecting large scale networking science and environment of large distributed systems.

## MAPPING TO NATIONAL OBJECTIVES AND NIST COMPETENCIES

A focus in Green Communications directly ties to National and global emphasis in improving energy usage and the vision for energy independence. The scientific and technical requirements for such a program also correlate to NIST's core competencies.

There can be no doubt to the high importance placed on energy related research in recent years. The new Administration has placed Energy as a critical national need as evidenced by the *Obama-Biden New Energy for America Plan* [10]. While the President's Council of Advisors on Science and Technology (PCAST) *Energy Imperative Report* to the President has stated that maintaining progress in realizing Federal energy policies will "depend on major improvements in technologies" and "require fundamental breakthroughs in technology innovation" [11] .

While there is considerable emphasis and funding for energy research [12, 13] there is no focused effort directed to a systemic analysis of green communications at the national level.

*Alignment with NIST Technical Areas*

An interdisciplinary approach addressing energy optimization for wireless communications that encompasses physical layer, access control, and networking has synergy with existing NIST programs and aligns with technical core competencies in test and measurement research. The Advanced Network Technologies Division (ANTD) of NIST currently has focus areas in Seamless and Secure Mobility, Robust Mobility and Wireless Networks, and Measurement Science for Complex Information Systems [14]. Green Communications strategies will depend on adaptable power techniques for mobile users [15, 16]. Similarly, solving this problem requires a global view of each device and network's complex interactions within the power grid. NIST's current domain expertise in Complex Systems dovetails with this paradigm [17, 18]. Finally, NIST's current research in wireless ad-hoc networks utilizes a multidisciplinary vision integrating networking with physical layer components correlating with the ideas presented here [19].

## MEETING TIMELY NEEDS NOT MET BY OTHERS

*Overview*

Given the incredible scale and importance placed on energy related research, there is significant efforts currently in progress and planned. However, on the federal level, these efforts are more broadly focused on traditional energy topics such as hybrid electric vehicles, alternative sources of energy, improving distribution, and efficient construction. The efforts focusing on green wireless communications are primarily industry driven and typically narrowly defined in the physical component level. There is need for a government led programmatic strategy that addresses green communications from an interdisciplinary and cross layered approach.

*Summary of Existing Efforts in Green Communications*

A review of existing efforts has shown little programmatic focus on green communications. Government programs such as *ENERGY STAR* have provided administrative guidance in reducing power consumption of devices such as appliances. Recent efforts have addressed the growing impact of information technology associated with data centers [20] and are defining metrics associated with large data center energy efficiency [21]. Global coalitions such as eSustainability Initiative call for similar broad directives such as Smart motors, Smart logistics, Smart buildings and Smart grids [22].

The electronics industry has placed significant urgency on improving energy efficiency yet these programs are narrowly focused and lack a broad programmatic guidance. For example, two industry coalitions, the Silicon Integration Initiative and the Power Forward Initiative are supporting low power design [23, 24], while the major IT companies are addressing computer power interfaces [25]. The telecommunications industry has only recently taken a regulatory stance in addressing green communications, yet here too there is a short sighted vision with little focus on interdisciplinary approaches and technical rigor [26]. The European coalition, eMobility's 2008 newsletter lists member research focus priorities as "new materials, energy efficient radio, and more flexible business models" [27]. While large telecommunications providers such as Vodafone have broadly pledged to reduce their carbon emissions by 50% by

2020 [6] only to see their actual usage rise by almost 17% [4]. The winner of this year's Green Mobile Award at the Global Mobile conference was a service provider that utilized a low risk renewable energy sources to power base stations off grid [28]. While these efforts show a commitment to the vision of green communication, a much more strategic, high-risk/high reward visionary effort is required.

Additionally, in their 2007 Report, PCAST has identified as a top priority the need to overcome traditional design philosophies related to the integration of cyber and physical systems [29]. This paradigm shift directly correlates to the Green Communication's emphasis on cross layer design analysis that ties together physical layer with the medium access and networking layers. The National Science Foundation has recently requested proposals in the area of Cyber Physical Systems [30], however more emphasis has been placed on major theme areas such as transportation, medical systems, finance and overall energy research.

*TIP's Role*

A TIP managed Green Communications program would enable a complete solution that breaks through the currents status quo of a vertically separated design mentality. Current efforts in Green Communications are narrowly focused at individual component level while National visions in energy and cyber-physical systems are too broad to provide any substantial solutions. The technical and scientific foundations of Green Communications combined with the requirement for specific metrics of assessment and measurement techniques makes this topic ideally suited for NIST and the TIP program.

## CONCLUSION

The development of scientifically rigorous definitions and metrics for Green Communications is a critical national need that is not currently being met by other agency efforts or through industry action. Only an Administrative lead programmatic interdisciplinary endeavor founded in the methodical technical rigor can truly create transformational results. We feel that Green Communications meets criteria of a high-risk/high-reward, research program worthy of TIP (Table 1).

**Table 1 Mapping Green Communications to the foundations of TIP**

| | Maps to Administration Guidance | Justifies Government Attention | Meets essentials for TIP funding |
|---|---|---|---|
| **Developing Metrics and Measurement Science for GREEN COMMUNICATIONS** | Synergy with Presidential Administration's emphasis on energy and PCAST's energy initiative. Dovetails with several NIST programs | Current efforts are narrowly focused with falling into traditional design paradigms or are public relations and marketing driven. | *Transformational* because the research traverses across the entire design stack and breaks through traditional architecture paradigms. This program has the potential to improve our understandings of large distributed multi-agent networks.<br><br>*Societal Challenges* include overcoming the status-quo of existing vertical separation between layers and potential for radical environmental impacts given the ubiquitous growth rate and society's demand for 24/7 broadband. |

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