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A survey on Wireless Grids and Clouds

Gang Li, Hongmei Sun, Huahao Gao, Haiyan Yu, Yue Cai
Institute of Computing Technology
Chinese Academy of Sciences
Beijing, China
e-mail: ligang@ict.ac.cn

***Abstract*—Wireless grid is a wireless network based virtual system that consists of wireless-connected different types of electronic devices and computers. It has broad application prospects in e-learning, mobile e-business, modern healthcare, smart home, wireless sensor networks and disaster management. Wireless cloud is a natural extension of wireless grid. On the basis of a literature analysis, this paper gives a category on wireless grids, and discusses the concept, characteristics and architectures of wireless grids. Then it presents a review on the existing work, mainly focusing on the issues of communication technologies, middleware and applications. At the end, the paper analyzes the open issues and lists the main research directions in this field. The survey indicates that the wireless grid and cloud is a vibrant research area.**

Keywords-wireless grids; wireless clouds; wireless networks; wireless ad hoc networks

I. INTRODUCTION

Ian Foster et al. defined the grid problem as coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations [1]. Grid computing combines the technologies of distributed computing, networks, servers and storages, and supports resource sharing across different organizations. With grid computing technology, one can integrate the distributed resources of servers, storage devices and networks into a super virtual computing system, and solve the "grid problem".

The term grid computing was proposed by Ian Foster and Carl Kesselman in the early 1990s. After almost 20-year development, grid computing has many varieties, such as computing grid, data grid, access grid, information grid, service grid, wireless grid and cloud computing.

Wireless grid is a wireless network based virtual system that consists of wireless-connected different types of electronic devices and computers. In Wikipedia, it is defined as ad-hoc, distributed resource-sharing network between heterogeneous wireless devices. By wireless links, a wireless grid augments the wired grid. It resembles the networks already founded in connection with agricultural, military, transportation, air-quality, environmental, health, emergency and security systems [2].

While people increasingly use more small and smart devices in their personal and professional lives, wireless grids have wider variety of possible applications. L. W. McKnight et al grouped wireless grid applications into three categories:

- Applications collecting data from nomadic devices
- Location-related applications
- Applications using wireless network connected devices

These applications have a close relationship with wireless sensor networks and wireless ad hoc networks.

According to Wikipedia, the cloud represents a computing style in which dynamically scalable and often virtualized resources are provided as a service over the Internet. It includes the concepts of IaaS (Infrastructure as a Service), PaaS (Platform as a Service), SaaS (Software as a Service) et al. Many existing cloud systems depend on grid infrastructures. Now, the web applications of Google and Amazon are powered by clouds.

Wireless cloud is a natural extension of wireless grid. It provides seamless access to Internet, networked devices and computing capacities. Some researchers thought there are not much difference between wireless grid and wireless cloud. In this paper, we regard wireless cloud as a kind of next-generation wireless grid. Wireless cloud is an emerging technology, and the publication on it is limited.

In this paper, we analyze the existing work, and discuss the concepts, characteristics and infrastructures of wireless grids. Furthermore, we give the state of the art and open issues in this field.

The rest of this paper is organized as follows. Section II summarizes the existing work. Section III lists the characteristics of wireless grids. Section IV presents the wireless grid architectures. Section V analyzes the status quo of wireless grid research. In section VI, we draw our conclusions and give the research directions.

II. SUMMARIZATION ON WIRELESS GRIDS

To catch the latest status and the research trends, we retrieved and collected the papers on wireless grids and clouds with the search engine Google Scholar. The statistics of the papers is presented in Figure 1.

As Figure 1 shown, the earliest papers on wireless grids were published in 2002. Overall, the number of the papers sustainably increased from 2002 to 2008. The number of papers peaked in 2006. The papers published in 2006 accounts for 20.5% of all the publications. In 2007, the number of papers dropped a little. That year, cloud computing became a buzzword. More researchers focused on

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cloud computing technologies. In 2008, wireless cloud computing emerged. And the number of papers on wireless grids and wireless clouds reached another peak, and accounted for 20.5% of all the publications.

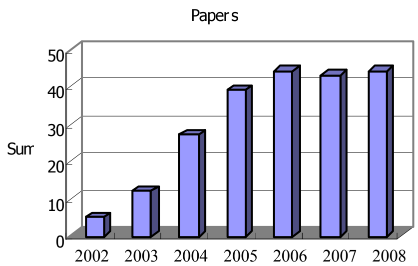

Figure 1. Papers on wireless grids and clouds increased during 2002 ~ 2008

Compared with the publications on data grids, access grids et al., the number of paper on wireless grids is still much smaller. The analysis on the publications indicated the existing work of wireless grids mainly focused on the topics of communication technologies for wireless grid, middleware and applications.

Referring the grid classification proposed by Heba Kurdi et al., we give a category of wireless grids according to their accessibility and interactivity. Table I. lists the category.

B. *Resource constrained devices*

High resource-consuming devices, like high performance servers, mass storage devices, are very common in computing grids, data grids, access grids and other traditional wired grids. But in wireless grids, the low-powered small devices, like sensors, smart phones, digital cameras, PDAs and laptops, are more popular. Most of them are battery-powered. Their storage and computing capabilities are also limited.

C. *Heterogeneous components*

Grid facilitates sharing of heterogeneous resources [21]. The evolution from PCs to smaller and mobile devices with computing capabilities brings more heterogeneous devices and applications into wireless grids. Wireless grids have to manage and support the inter-organizational applications that consist of more heterogeneous components from autonomic devices.

D. *Dynamic resources and requirements*

In wireless grids, the users, resources, requirements and computing environments are dynamic. The wireless networks are inherently volatile, due to their unstable wireless communication medium [19]. In addition, the changes of natural environment also influence the wireless networks. In wireless grids, mobile users are common. And the users use mobile devices increasingly. Due to the ad hoc mode, the users and resources can join and quit the grid conveniently. The flexible resource sharing and coordination mode inspire the users to spontaneously raise their requirements for new applications [24].

TABLE I. A CATEGORY ON WIRELESS GRIDS

Category	Differences	Potential applications	Examples
Ad hoc wireless grids	Support P2P connections, have no predefined entry points	Disaster management applications, mobile collaborations, sensor network applications, device integration etc.	MoGrid
Mobile wireless grids	Support mobile clients, services or both	E-health, e-learning, device integration, mobilized enterprise information systems etc.	MORE, Akogrimo, MoGrid, MiPeG
Context-aware wireless grids	Support context-aware interactions	Sensor network applications, pervasive grid applications etc.	MiPeG

III. CHARACTERISTICS

Wireless grids are on the basis of wireless networks. But the communication infrastructure is not only the difference between wireless grids and traditional wired grids. Wireless grids have the following distinguishing features:

A. *Ad hoc mode*

Wireless networks, especially wireless ad hoc networks, facilitate the on-demand integration of heterogeneous devices. The ad hoc connected devices have no centric control. It makes the wireless grid more dynamic and brings more convenience to resource sharing and coordination. At the same time, the ad hoc mode also brings more challenges of security, resource discovery and trusted resource management to wireless grids.

IV. ARCHITECTURES

S. P. Ahuja et al thought that wireless grid architectures could be classified into the following categories according to the predominant devices and device mobility [3].

- Wireless sensor grid architecture
- Mobile wireless grid architecture
- Fixed wireless grid architecture

The wireless sensor grid integrates wireless sensor networks and traditional grid computing technologies [4]. The applications are designed around the data from the sensors. And the sensors play an important role in this kind of wireless grid architecture. On the basis of wireless sensor network infrastructures, it adopts the technologies of data grids, computing grids and access grids to storing, processing, presenting and sharing the data collected from the sensors.

The mobile wireless grid has much more mobile devices, such as mobile phones and PDAs. In addition, the users are also mobile. The network infrastructure is mobile ad hoc network. The devices participate in the mobile wireless grid as data collectors or client nodes. In most cases, these devices are mobile wireless access clients. They can freely enter and leave the wireless grid together with their mobile users.

The fixed wireless grid has no difference with traditional wired grid, except the communication medium is wireless.

In practice, besides the pure wireless network infrastructure, a hybrid network infrastructure is more commonly used in wireless grids, where the wireless networks are connected with wired networks.

Figure 2 depicts an architecture that integrates the wireless grid with wired network backbones. In this architecture, the high resource-consuming devices, such as high performance servers and mass storage devices are connected by high speed wired networks; the small or mobile devices are integrated by wireless ad hoc networks. This hybrid architecture makes up the lack of resources in wireless grids.

Taking one with another, the architecture of a wireless grid can be divided into four layers: physical layer, communication layer, middleware layer and application layer.

The physical layer covers all the devices involved in the wireless grid. The communication layer chains the devices with wireless networks or connects the wireless-linked devices with wired networks. The middleware layer takes charge of resource description, resource discovery, coordination and trust mechanism, and supports development of wireless grid applications. On the basis of middleware layer, the application layer includes a variety of wireless grid applications, such as health care systems, environment surveillance systems, seismic monitoring systems and so on.

Figure 2. Hybrid wireless grid architecture

V. State of the Art

A. Wireless communication technologies

Many wireless communication technologies are used in wireless grids, to provide wireless interfaces to connect high-bandwidth powered PCs and low-bandwidth powered smart devices. These technologies include IEEE 802.11x, IEEE 802.16x, IEEE 802.15x, IEEE 802.20x, Zigbee, Bluetooth, wireless ad hoc networks et al.

1) IEEE 802.11x

IEEE 802.11 is a set of protocol standards proposed by the IEEE LAN/MAN Standards Committee. The protocol family includes 802.11a~z. They support wireless local area network communications in the 2.4, 3.7 and 5 GHz frequency bands. The first version of IEEE 802.11 protocol was released in 1997.

The 802.11 protocols are very similar with the 802.3 protocols. In fact, they are wireless Ethernet protocols. The 802.11 protocols cover the physical layer (PHY) and the media access control layer (MAC) of the data link layer. Different from the 802.3 protocols, the 802.11 protocols use CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) technologies instead of CSMA/CD (Carrier Sense Multiple Access with Detection) at the MAC layer, to meet the requirements of wireless communications.

Wi-Fi (Wireless Fidelity) is a trademark of the Wi-Fi Alliance. The Wi-Fi technologies cover the protocols of 802.11a, 802.11b, 802.11g and 802.11n, and can be used in mobile phones, home networks and other devices that are connected by wireless networks. With Wi-Fi, one can construct flexible wireless networks in infrastructure mode or ad hoc mode. These 802.11 based networks equip wireless grids with fundamental communication facilities.

2) IEEE 802.16x

The protocol family of IEEE 802.16 was proposed by the IEEE LAN/MAN Standards Committee also. It includes 802.16a~k et al, which are the standards of broadband wireless access. The IEEE 802.16 protocols support wireless communications in the frequency bands of 10~66 GHz. The first protocol standard of IEEE 802.16 was approved in 2001.

The IEEE 802.16 defines the standards of protocols at the physical layer (PHY) and the media access control layer (MAC). These protocols support both mobile access and fixed access. At PHY layer, the 802.16 adopts the technologies of OFDM (Orthogonal Frequency Division Multiplex) and OFDMA (Orthogonal Frequency Division Multiple Access). OFDMA can flexibly adapt to requirements changes of bandwidth. With fixed sub-carrier frequency interval and symbol time, it reduces the impacts of changes at PHY layer on the MAC layer also.

Different from the IEEE 802.11 protocols that support WLAN (Wireless Local Area Networks), the IEEE 802.16 protocols focus on WWAN (Wireless Wide Area Network). They use TDMA (Time Division Multiple Access) at MAC layer, instead of CSMA. In addition, the protocols have three sub-layers at MAC layer: service specific convergence sub-layer, common part sub-layer and privacy sub-layer.

In addition, the IEEE 802.16 protocols have more choices on bandwidth and frequency, and have higher transmission power. It makes them more suitable for the wireless grids that need wide area wireless networks.

WiMax (Worldwide Interoperability for Microwave Access) is a technology based on the IEEE 802.16. It supports 802.11d and 802.11e. Similar to Wi-Fi, WiMax can connect handsets, PC peripherals and embedded devices. As a backhaul technology for 3G(Third Generation) and 4G(Fourth Generation), WiMax is a promising technology for constructing wireless grid.

3) Wireless ad hoc networks

The ad hoc is an organization mode of the wireless network nodes. A wireless ad hoc network consists of a group of autonomous nodes that communicate with each other in a decentralized manner. Each node of the network connects others with wireless links, and acts as both a host and a router. The nodes can join or quit the network freely. Therefore, the topology of wireless ad hoc network is dynamic. The decentralized nature makes the ad hoc network more suitable for wireless grid.

According to applications, wireless ad hoc networks are classified into three categories:

- Mobile ad hoc networks

  Mobile devices connect each other in a self-configuring way.
- Wireless mesh networks

  Nodes are organized in mesh topology. In most cases, the nodes of wireless mesh networks are static.
- Wireless sensor networks

  Nodes are distributed autonomous devices that can monitor environmental conditions. Wireless sensor networks are typical tools for data collection in wireless grid.

Wireless ad hoc networks provide wireless grids with ubiquitous untethered communication, and allow wireless devices to discover and interact with each other in a P2P manner. With a special purpose gateway, an ad hoc network can bridge to wired LANs or to the Internet. It facilitates the integration of wireless grids and traditional grids.

Discovering and maintaining available routes is a key issue of wireless ad hoc networks. Although there are several routing protocols (such as AODV, DSR, ZIP, AOMDV et al), it still needs more efforts to provide adaptable routes for resource discovery in wireless grids.

B. Middleware

As well-known, traditional wired grids suffered the problems caused by heterogeneous resources and requirement changes. To solve the problems, many efforts have been made on traditional grid middleware. Regarding wireless grids, the problems are more serious, due to the dynamic characteristics. Meanwhile, the wireless grid middleware faces other challenges, for example, limited power, high-latency connectivity and unstable wireless connection.

This section reviews the typical work on wireless grid middleware.

- Akogrimo

The FP6-IST program supported the research on Akogrimo which enables access to knowledge through wireless grids. Some systems of e-learning, disaster management or e-health used the middleware Akogrimo.

Akogrimo supports wireless grids with mobile grid clients. It provides fixed, nomadic and mobile users with mobile grid services. On the basis of Akogrimo, grid services can be dynamically composed in an ad hoc way. Figure 3 presents the architecture of Akogrimo.

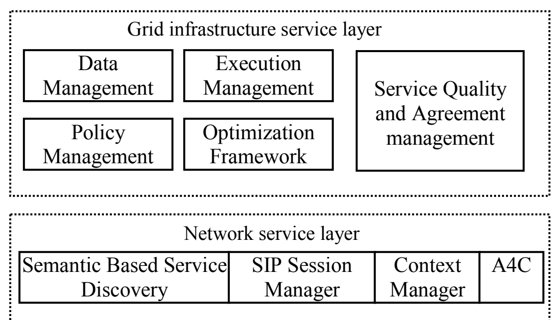

Figure 3. Akogrimo architecture

The middleware consist of two logical layers: network service layer and grid infrastructure service layer. The network service layer is constructed on a mobile IPv6 based infrastructure. It provides network services like Authentication, Authorization, Accounting, Auditing and Charging (A4C). With a QoS Broker, the network service layer enables context driven selection of different bandwidth bundles. On the basis of the network service layer, the grid infrastructure service layer provides service oriented facilities for wireless grid applications [5]. It includes the business partner management, service quality management, business process execution management and mobile virtual organization management.

The middleware Akogrimo transplants lots of traditional grid technologies (such as virtual organization management, grid workflow) to wireless mobile environments, and enables the awareness of the mobility of virtual organization members.

- MORE

Andreas Wolff et al. designed the middleware MORE which adapts web services for embedded systems. The middleware facilitates construction of mobilized enterprise information systems.

MORE combines technologies of embedded systems and web services to facilitate the integration of heterogeneous devices. It hides the complexity of heterogeneous embedded systems with unified and simplified interfaces. MORE also supports scalable group communication, where the small devices such as sensors and smart phones can connect with each other through wireless networks. With MORE, application developers can deploy ubiquitous services on embedded devices, and share the services within a group.

The key blocks of MORE include core management service and application enabling services. The core management service adopts group management concept, and uses XML-based policies to create and configure groups to control the behavior of group participants. The enabling services implement the service functionalities and provide fundamental supports for the applications [6].

The middleware MORE uses connectors for the communication between the enabling services. The connectors include internal connectors, proprietary connectors, SOAP connectors and µSOA connectors. The proprietary connectors and µSOA connectors support the embedded device involved services. The µSOA connectors enhance the efficiency of mobile embedded devices. By the µSOA approaches, MORE reduces the resource consumption in wireless grids.

- MoGrid

Luciana dos S. Lima et al. designed the middleware MoGrid, which supports grid services in wireless ad-hoc networks. The middleware has much application potential in mobile collaborations.

MoGrid orchestrates the distributed grid tasks among mobile devices in a P2P manner, and uses a resource discovery protocol named P2PDP to coordinate tasks among the most resourceful and available mobile devices. MoGrid offers application-level mobility transparency, and supports the development of context-sensitive applications for mobile collaborations [7].

MoGrid leverages the resource coordination in wireless ad hoc networks by allocating the tasks for a group of mobile collaborators. The coordination consists of two phrases. First, the P2PDP protocol discovers the resources that the coordination needs. Second, a collaborator submits the tasks to the participants according to the available resources they have [7].

As shown in Figure 4, the MoGrid architecture comprises a P2P discovery layer and a transparency layer. According to the application basis, the applications are categorized into standard applications and MoGrid-tailored applications. The P2P discovery layer includes entities of collaborators, coordinators and initiators, and supports the resource registration and announcement, context definition, and resource discovery. After the devices register resources in MoGrid, they become collaborators. The registered resources are accessible to other devices in the MoGrid-enabled wireless grids. The initiators request the collaborators for task processing. The coordinators broadcast the request of initiators for resource discovery and coordinate the collaborators and initiators to complete the tasks. The transparency layer handles the resource coordination among collaborators. It consists of two sub-layers: adaptation sub-layer and transparency resource access sub-layer (TRAS). TRAS provides application-independent transparency for resource utilization. The adaptation sub-layer handles the mobility and connection-related events for each specific application.

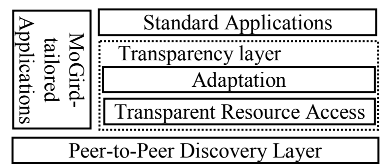

Figure 4. MoGrid architecture

MoGird tackles the issues of resource discovery and collaboration in wireless ad hoc networks. But its resource discovery protocol P2PDP should be improved further, in order to solve the problems caused by device mobility and transparency contexts [7].

- MiPeG

Mario Ciampi et al. designed the middleware MiPeG which enhances classic grid environments with wireless mobile mechanism. This middleware can be used in pervasive grid applications.

MiPeG enables integrating traditional grids and wireless devices. With a group of fundamental services, MiPeG enables deploying grid service clients on wireless mobile devices, and provides context-awareness for the applications. In addition, it can allocate user's tasks to different mobile devices also. In a MiPeG-powered grid, the mobile devices can be either active resources or grid service clients. When the MiPeG-powered mobile devices enter, the grid can automatically recognize the devices and coordinate them in applications.

MiPeG is a service-oriented middleware. As shown in Figure 5, it consists of a set of basic services which are compliant with the OGSA specifications.

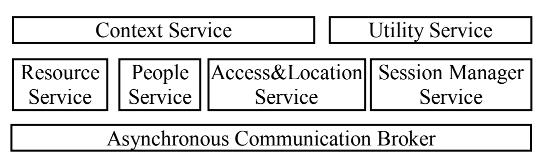

Figure 5. MiPeG architecture

In MiPeG, the asynchronous communication broker implements the WS-Brokered Notification specification, and provides an interaction mechanism based on the event publish-subscribe paradigm. It dispatches asynchronous messages in the grid. The resource service manages the grid resource registration, and enables the integration of wireless devices (such as PDAs and sensors) in the grid. The people service provides the mobile users with basic authentication mechanisms. The access and location service supports accessing to 802.11-enabled mobile devices. In addition, it can locate the position of the mobile devices also. The session manager service handles the sessions for mobile users. The context service offers the context information including the state of resources, mobile user locations and users' profiles. The utility service implements the utility computing model, and accepts the tasks submitted by users for execution. With the utility service, the users can complete a task without considering the issues of reserving/releasing resources et al.

MiPeG mainly focuses on the integration of mobile devices and traditional grids. It does not solve the problems of dynamic device changes well. In addition, MiPeG uses service-oriented technology, but its supports to deploying the services on the resource-constrained mobile devices are still weak.

C. *Applications*

Wireless grid technologies have broad application prospects in many fields. The applications include wireless sensor grids, environment data collection, e-health, e-learning, wireless-linked device integration and so on. This section analyzes the typical applications of wireless grids.

- Wireless sensor grids

The emerging sensor technologies increasingly support many application areas. Wireless sensor grids combines wireless grids with sensor networks. It facilitates the transfer of information about the physical world around us to a plethora of web-based information utilities and computational services [17]. Wireless sensor grids can be used widely in disaster early warning and environment surveillance et al.

GridStix [18], Equator [20] and Floodnet [22] are three systems that use technologies of sensors, wireless networks and grids to monitor flood and provide early warning. In these systems, a variety of sensors equipped with wireless networking technology form a lightweight grid which is capable of collecting and transmitting data about flood disaster [18]. The lightweight sensor grid connects with traditional grid infrastructure which analyzes the data gathered by the sensors for flood warning.

Besides the above mentioned, there are also wireless grid based supply-chain management system, for example, the Smart Warehouse system. The Smart Warehouse is a prototype of supply chain management system equipped with a wireless sensor grid [17]. With the smart sensor, it can track the items in the warehouse and identify problems in the supply chains.

- e-Healthcare

In healthcare field, wireless grids can integrate a variety of medical devices (such as vital signs sensors) and provide a personalized healthcare service delivery paradigm which always requires a one-to-one connection between the patient and the medical expert [9]. Besides the personalized services, the wireless grid based e-healthcare systems can integrate the healthcare services into the patient's environment, forming a network of mobile and stationary monitoring and diagnosis facilities around the patient. By this means, medical professionals can establish an inter-organizational virtual hospital, and provide efficient detection of health emergencies and pervasive healthcare.

The Heart Monitoring and Emergency Service (HMES) system is an Akogrimo-based e-healthcare platform. It integrates the patient monitoring, emergency detection and subsequent rescue management, and enables an early recognition of heart attacks or apoplectic strokes and a proper treatment of patients as fast as possible [10].

Besides HMES, there are other wireless grid powered e-healthcare systems, for example, MobiHealth [11], Rural e-Healthcare Framework [12] and Hourglass [17].

- e-Learning

Wireless grid technologies facilitates e-learning. Take the wireless grid middleware Akogrimo as an example. Akogrimo enables almost universal availability of mobile devices to education and training. In an Ahogrimo-based e-learning system, the learners can use handheld devices to get learning contents from the wireless grid. And they can engage them in purposeful activity, problem solving, collaborations, interactions and conversations [13].

The e-Campus system is another example of wireless grid powered e-learning. It adopts wireless grid technologies and supports mobile learning [14]. Based on grid service technology, the mobile learning combines traditional grids with mobile devices, and facilitates the sharing of learning resources distributed on different e-Learning platforms [15].

- Wireless-linked device integration

Wireless grid technologies facilitate developing the applications which focus on integrating wireless-linked small devices. Take IMOGA as an example. IMOGA supports integrating mobile devices into a grid system, and sharing/producing information in a cooperative manner [16]. In IMOGA, the mobile devices, such as PDAs and smart phones, employ different kinds of sensors to collect data, such as Global Positioning System (GPS), temperature monitoring components, health monitoring systems and pollution monitoring components. The gathered data is shared between huge numbers of mobile devices and high capacity grid infrastructures where the developers can construct applications of e-healthcare, e-crisis management and e-government [16].

VI. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Wireless grid is a wireless network based virtual system that consists of different types of electronic devices and computers. This paper presents a survey on wireless grids, including the concept, characteristics, architecture and key technologies of wireless communication technologies, middleware and applications.

It indicates that the wireless grid is a vibrant research area and has broad application prospects in the fields of wireless sensor grids, environment data collection, e-health, e-learning, wireless-linked device integration and so on.

In the future, more effort should be made at the following aspects:

- Although some significant work was done, most of the existing wireless grids were built on fixed wireless infrastructures [7]. Wireless ad hoc networks support dynamic device integration better. In the future, ad hoc networks will play important roles in wireless grid construction. And efficient methods for resource discovery and integration in ad hoc networks will benefit wireless grids.

- Integrating wireless grids with existing information systems or traditional wired grids raises new challenges in terms of routing, aggregating and querying diverse data on the wireless connected heterogeneous devices [17]. Much effort should be made on this topic.
- Wireless grids are not just only next generation networks. With the pervasive devices, wireless grids have more complex relationships with applications and social environments. The interesting socio-economic-technical challenges are therefore about the dynamic inter-operation, integration and disintegration of networks, applications and users, in real time in wireless grid environments [23].

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