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Analysing the effect of security on information quality dimensions

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ANALYZING COMMUNITY CONTRIBUTIONS TO THE DEVELOPMENT OF COMMUNITY WIRELESS NETWORKS

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Abstract

Community wireless networks (CWNs) have emerged as collective actions achieved by many communities worldwide to access the information highway. Developing autonomous CWNs depends, in large part, on community contributions that may include time, money, efforts, expertise and computer resources. However, there is a lack of instruments for measuring such contributions, as well as the outcomes of these networks. This study uses the social network analysis analytical approach to model, measure and analyze community contributions in the development of their wireless infrastructures. In particular, we model community contributions as a two-mode (or bipartite) graph composed of two sets of nodes: the first represents a set of community contributors and the other represents a set of wireless networks. The edges between these two sets stand for the inputs of contributors. Their contributions include volunteering time and manpower, sharing their wireless nodes with community members, donating money, donating hardware, providing technical support, and developing open source software for the network. The model is used to analyze these tangible and intangible forms of contributions. We hope this study provides a better understanding and sounder measurement of the role of communities in developing these emerging common wireless infrastructures and similar digital collective actions.

Keywords: community wireless networks, social network analysis, collective actions, common systems

1. INTRODUCTION

The phenomenal growth of community wireless networks (CWNs) has captured the attention of a broad range of academicians and professionals in several disciplines and practical fields. CWNs are socio-technical crucibles where community resources are shared, mobilized and reproduced to build a common telecommunication infrastructure. Numerous communities have built autonomous wireless infrastructures using their own resources to join the information society. The majority of these networks provide free, or affordable, Internet to community members. In other words, CWNs have been built by the community, as an outgrowth of private WLANs, for the community. We argue that CWNs could serve as a third solution, in addition to the private and public solutions, for achieving digital inclusion (Abdelaal and Ali 2009a). Consequently, scholars recognize them as *wireless commons* achieved by *collective actions* (Abdelaal and Ali 2009b; Bina and Giaglis 2006; Damsgaard, Parikh, and Rao 2006; and Sicker, Grunwald, Anderson, Doerr, Munsinger and Sheth 2006 and Negroponte 2002). The term *collective actions* refers to the voluntary collaboration of group members to construct a common project (Olson 1971:pp7). Literally, a collective action requires a collectivity, or a group of people, which collaborate to achieve an action (Sakurai 2002). Along this notion, developing collective wireless networks, require a motivated and committed group of agents, sometimes organizations, with shared objectives who contribute to these networks for the well-being of the community at large (Abdelaal and Ali 2007; Quinn 2006; Bina and Giaglis 2006 and Camponovo and Cerutti 2005). These agents may include local residents, open source software (OSS) developers, students, technology vendors, municipalities, civil rights activists, developing agencies and researchers.

Agents of a social structure are those who participant in converting both tangible and intangible resources into negotiable offerings (Allee 2008). The agents of CWNs could be classified into three categories: beneficiaries, contributors, and isolated actors (Abdelaal and Ali 2008). Beneficiaries are individuals who gain from these collective networks. Their benefits may include obtaining free Internet access, donated old PCs, technical expertise, exposure, and/or other social gains. Contributors are those who donate to the network. Their contributions may include providing manpower or technical skills, donating money or used equipment, sharing their wireless nodes with others or boosting the publicity of the project (Quinn 2006 and Drunen, Koolhaas, Schuurmans and Vijn 2003). Scientists and practitioners emphasize that engaging community members and employing their resources are essential to building and sustaining these community-driven ventures (Siochrú and Girard 2005; and Sandvig, Young, and Meinrath 2004 and Bina and Giaglis 2006). Isolated actors, within the proximity of the network, are those who neither benefit from nor contribute to the network. These isolated actors include the "have-nots" or those who are digitally disconnected. The subject matter of this paper is the contributions of the agents of CWNs to the development and operation of these collective actions. CWNs provide community members the opportunity to contribute (e.g. money, time, expertise, computer resources) and develop innovative applications, software, and hardware for their communities (Powell 2006). In this study, we use the term contributions to refer to the tangible and intangible resources or assets provided by community members to build and maintain CWNs.

Despite the exponential growth of these networks, closely linked to the deregulation of the 2.4GHz spectrum, there is a lack of empirical studies and quantitative methods that investigate their resources and outcomes. For instance, previous attempts, mostly case studies, have conceptual and instrumental limitations. Our objective is to complement previous literature and develop a quantitative model, supported by empirical evidence, for community contributions to CWNs. Hopefully this model would guide future research and help policy makers and community developers to promote this innovation. Such collective projects, we believe, require new perspectives to treat their resources and outcomes for the following reasons:

1) CWNs are built and operated by flows of tangible (e.g. money, hardware) and intangible (e.g. knowledge, efforts, and software) contributions from community members. Since these contributions are provided for free, it is difficult to measure and aggregate them using conventional measures. Therefore, it is hard to comprehend the contributions of these resources to the overall cost of the project;
2) Most of these networks are not official organizations, but rather loosely affiliated groups or collectivities;
3) As with other collectivities and collaboration groups, it is not easy to track the contributions and benefits of participants. This problem is exacerbated if the diversity of stakeholders of CWNs is considered; and
4) Community contributions, and the benefits of CWNs, are usually provided outside the market mechanism. Therefore, it would be useful to convert them into negotiable market values in order for researchers to control such factors and for practitioners to manage their networks.

Therefore, paying special attention to this emerging form of collective actions is warranted and developing quantitative models or metrics for their variables is necessary to advance this intellectual stream and accumulate related knowledge. The developed models, or artifacts, should be efficient and general enough to encompass different types of involved actors and acknowledge their contributions and benefits. The key question we address is:

How can we measure the role of communities in developing their wireless networks?

Social network analysis (SNA), depends on graph theory, is used to answer this question. Answering this research question is important for understanding how community resources are mobilized and reproduced to achieve collective actions, taking advantage of digital innovations. This would be a first step towards advancing CWNs as a third solution to integrate the society in the information age. This analytical approach has been used to study a wide-range of similar networks such as computer, social, biological, chemical and transportation systems (Hanneman and Riddle 2005 and Peter, Scott, and Wasserman 2004). Sufficient modeling and analytical details are provided so that researchers and practitioners can apply the adopted research approach in their own investigations. This study is part of a larger research project whose objective is to investigate the tension between these emerging socio-technical networks and their societies. Investigating the tension between "structure and agency" or "macro and micro" is one of the key intellectual themes in sociological inquiry (Hanneman and Riddle 2005). It is important to note that this paper is an extension to a previous work that proposes a conceptual framework of community contributions to CWNs (Abdelaal, Ali and Khazanchi 2009b). In this previous work, we treat community contributions as collective actions mobilized by the social capital in the community. In another work, we explore the role of these networks in achieving digital inclusion for their communities (Abdelaal and Ali 2009a). In particular, we also discuss their size, capacity, service charging, and finances. We also provide a thorough review of literature related to their outcomes

The rest of this paper is organized as follows: section 2 discusses the literature of the role of communities in building their wireless networks and briefly reviews similar work that uses SNA to study complex networks. In section 3, we present our research methodology. In section 4, we propose our model. In the fifth section, we use the proposed model to compare and classify CWNs. Section 6 discusses the significance of research and suggest ideas for future work.

2. LITRATU RE REVIEW

The notion of community and information commons have attracted the attention of a large number of Internet scientists (Lesser, Fontaine and Slusher 2000). Although there is an extensive research on collaboration in the domain of the Internet, very little empirical work has focused on the creation of telecommunication infrastructures as outcomes of such collaboration. In other words, a small body of research, mostly qualitative, addresses how CWNs are built. For instance, Damsgaard, Parikh, and Rao (2006) describe CWNs as *wireless commons*. They define wireless commons as a group which share their private WLANs to create a common resource and open it for others. The authors point out that the group members might have conflicts of interest or they may overuse such a common resource. Misusing or overusing common resources is a classical problem in social science known of the *tragedy of commons*. They discuss the causes and the preventions of this tragedy in the domain of the wireless commons or CWNs. Sicker, Grunwald, Anderson, Doerr, Munsinger and Sheth (2006) use simulation tools to study the relationship between the network capacity and the number of users to examine if the wireless commons are misused. They use the density, usage patterns, environmental conditions, and application demand as assessment parameters. Battiti, Cigno, Sabel, Orava, and Pehrson (2005) call these networks *open access networks*. According to the authors, the main advantage of CWNs is fostering win-win partnerships between actors, increasing freedom of choice for users and providers, decreasing costs and expanding service coverage. Along this line of research, we also consider CWNs as a form of collective or common projects (Abdelaal and Ali 2009a and Abdelaal, Ali and Khazanchi 2009b).

In previous work, we propose a typology of the business models of CWNs that addresses the stakeholders, value offerings, target customers and resource management of different business models of CWNs (Abdelaal and Ali 2007). We classify these models into six categories and highlight the potential benefits and contributions of stakeholders associated with each model. In another previous work, we address the role of CWNs in achieving digital inclusion of their societies (Abdelaal and Ali 2009a).

Best and Maclay (2002) identify six factors that must be considered for designing a self-sustainable CWN: costs, revenue, networks, business models, policy, and capacity. Camponovo and Cerutti (2005) classify the actors of CWNs into four categories: (1) those who share their access points with others; (2) the beneficiaries of these networks who obtain free Internet access; (3) the Internet service providers; and (4) the regulatory authority that sets the regulations to govern the use of the spectrum. Bina and Giaglis (2006) use the concept of collective actions to explore the motivations of participants of CWNs. Mandviwalla, Jain, Fesenmaier, Smith, Weinberg, and Meyers (2006) identify the following stakeholders: underserved individuals, municipalities, schools, small businesses, nonprofit organizations, community groups, utility companies, healthcare providers, and state and federal governments. This study focuses only on the inputs of such stakeholder to CWNs. We discuss the outcomes of these networks in Abdelaal and Ali (2009).

Scholars point out that such inputs may include volunteerism, money and hardware donation, providing technical support and developing OSS for the network.

For instance, Quinn (2006) discusses the role of community engagement, volunteerism, OSS, and donated computer hardware in the development of three CWNs in the Chicago area (United States). The author also proposes a guide to help practitioners in this regard. Similarly, Drunen, Koolhaas, Schuurmans and Vijn (2003) point out the importance of community contributions in building and maintaining the Wireless Leiden network in the Netherlands. According to the authors, such contributions include low-cost network interfaces, OSS, home-built antennas, and voluntary manpower and technical skills. We model and analyze these types of community resources used to build the investigated CWNs. Using a case study, Shin and Venkatesh (2008) suggest that community participation should continue through all the developing stages is essential for the sustainability of CWNs They also identify four groups of stakeholders emerged around this network: the Kutztown municipal authority, technology vendors, the project team and the community. They argue that inputs of citizens, as lay designers, are important for the success of CWNs. Powell (2006) discuses contributions of volunteers to British Columbia Wireless. Their contributions include site surveys, hardware hacking, software and content development, technical support and legal and regulatory research.

Reviewing previous literature, we highlight the following drawbacks:

1) The types of community contributions, to CWNs, adduced in previous literature are plausible and supported by evidence from case studies. However, they are not categorized and attributed in terms of quantitative variables that could be controlled. This is important for guiding future research, allowing for comparison, and accumulating knowledge; and
2) There are no conventional instruments or common approaches to measure the tangible or intangible resources and outcomes of CWNs.

Similar to our analytical approach, Jackson (2003) discusses several examples of economic applications of graph theory. These applications include obtaining information about jobs from social contacts, exchanging goods between market actors, and contracting trade agreements. Gale and Kariv (2007) propose a graph model for financial networks where nodes represent traders and weighted edges represent the probabilities of trade between them. Souma, Fujiwara and Aoyama (2005) model the Japanese shareholders network using a directed graph where nodes represent companies and edges represent activities, ownership and governance. Spulber and Yoo (2005) use graph concepts to develop a pricing policy for telecommunication services. Their proposed pricing policy takes into account the impact of changes in one node on the entire system, particularly on the economies of scale. Tesfatsion and Pingle (2003) use graph concepts to examine the effects of a non-employment payoff on network formation and behaviors of workers. The authors model the interactions between networks of workers in a form of a directed graph. The vertices represent the workers and employers. Edges denote to the work flows between workers and employers. In our pilot study, we use data from the Omaha Wireless Group[1] to describe CWNs as socio-technical networks where each network is composed of two graphs: wireless network and a social network served by this wireless network (Abdelaal and Ali 20008). We argue that the interactions between these two graphs impact different aspects of CWNs. Evidently, graph theoretic concepts and SNA is a sounder analytical approach for studying CWNs as value networks.

2. RESEARCH APPROACH

As with similar emerging phenomena, there are no standard research approaches or widely-recognized empirical studies on CWNs. This is mainly because the CWNs movement is large and diverse, geographically dispersed, and informally structured. In addition, CWNs are not well-defined and practitioners and researchers usually mix between them and similar networks such as municipal wireless networks and commercial Wi-Fi hotspots (Abdelaal and Ali 2009b). It is, therefore, difficult to collect high quality data about the transactions of all actors. To avoid these problems, we collected 2-mode network data using a survey instrument during the annual International Summit for Community Wireless Networks (ISC4WN)[2]. The collected data represents a network of "affiliations" between different categories of community contributors, by their inputs to develop the network, and their CWNs. In other words, this data describes which type of contributor (e.g. volunteer, money donor, OSS developer, etc.) is affiliated with which CWN and how much he/she contributes. Another quality of the data is

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[1] The Omaha Wireless Group at http://omahawireless.unomaha.edu/index.html

[2] The International Summit for Community Wireless Networks was held in Washington, DC, U.S., May 28th to the 30th, 2008. Its objective was to explore the opportunities and challenges of CWNs.

that it represents 16 networks from different parts of the world. The data describes ties between two sets of nodes at two different levels of analysis: a set of CWNs on the micro level and the community members on the macro level. The third quality of the data lies in reflecting diverse opinions of CWNs developers and advocates who attended this annual summit. We posted the survey online and sent its link to those who could not fill it during the summit. We received 41 responses and eliminated the incomplete ones. The survey questions are designed to ask respondents to choose the types of contributions their networks receive from their communities. We categorized six distinctive facets of contributions (or variables): volunteering time, money donation, hardware donation, technical support, sharing access points, and developing software for the system, as shown in Table 1. These variables are used as proxies for community resources, or contributions. In order to study collective actions in a quantitative manner, we need to identify a collective action to examine and construct variables that represent this action (Sakurai 2002). These variables have been identified based on extensive review of literature, three years of experience working with the Omaha Wireless Group and discussions with leaders of CWNs. Seven individuals examined the clarity and relevance of the survey questions to the measured constructs. The literature and collected data shows that there are other types of contributions such as obtaining the necessary political support and promoting the awareness of the benefits of the project. We excluded such contributions for simplicity. Again, we use graph theory concepts to study how communities, by their contributions, create CWNs. A graph is a mathematical model consisting of two sets V and E. V is a set of nodes called vertices connected by a set of links (or E) called edges. Graphs have been used to represent many similar complex networks and solve related problems (Peter, Scott, and Wasserman 2004). The SNA and the UCINET software is used to visualize, measure and analyze the data. We adopt this approach for its efficiency in representing network data in a compact and systematic manner, suitability for computation processing, capability of using theories and concepts of graph theory and ability to infer patterns of relations between actors in a mathematical manner (Hanneman and Riddle 2005). For more details about concepts, measures and suitable data for 2-mode networks (or bipartite graphs), we refer readers to Hanneman and Riddle (2005) and Borgatti (2008).

4. MODELING THE CWNs-BY-CCONTRIBUTIONS NETWORK

		Time (h)	Money	Tech. supp.	access points	Hard. Dona.	OSS
1	Court Housing Co-op	5	200	10	100	50	0
2	SeatleWireless	100	5000	50	1000	0	0
3	Champain-Urbana	100	0	0	0	0	0
4	AirStream	250	10000	100	2000	500000	10000
5	PTAWUG	1250	7500	850	250	25	0
6	Keur Sedaro	15	30000	20	250000	0	0
7	Pretoria Wireless	0	3000	0	0	0	0
8	Cstle Square WiFi	300	60000	1000	0	0	0
9	WUG	500	6000	240	300	25	0
10	Cape Town Wireless	20	3895	400	300	500	0
11	Nepal Wireless	50	30000	100	1250	1250	0
12	Red Libre De Ometepe	25	30000	20	50	750	50000
13	Jawug	10	389	20	1500	0	0
14	NYCwireless	10	0	20	200	0	0
15	ZGwireless	100	0	200	5000	50	0
16	Digital el Paso	200	50000	400	1500	0	0

Table 1. A matrix of the contributions of CWNs actors

The investigated observations are transformed into a data matrix in which each observation, or a CWN, occupies one row and each variable, or type of contribution, occupies one column. Table 1 summarizes the data collected about these variables. Three kinds of intangible resources, or community contributions, have been distinguished in the realm of CWNs: the cooperation of volunteers, the technical expertise of computer specialists and the bandwidth shared by those who share their nodes with their neighbors. One of the challenging questions related to intangibles (e.g. human knowledge, software, reputation, political support, and collaboration) is how to convert them into negotiable forms of value (Allee 2008). Since community contributions are provided for free, we estimate their value using their opportunity costs. We assume that the opportunity cost of volunteered time is $5 per hour, the donated hardware (e.g. used computers and access points) is $25 per unit, the technical support is $10 per hour and the shared access point is $50 per unit. This process is called *value conversion* through which we convert intangible inputs or assets into financial values (Allee 2008). The third column in this table presents the dollar value of volunteered hours per week for the investigated projects. For instance, Court Housing obtains voluntarily time of $5(1x5) and SeattleWireless obtains voluntarily time of $100 (20 hours x 5 dollars). Column four represents the money donations received so far by these networks. Column five represents the dollar value of the weekly technical support provided to these networks by community members. For instance, SeattleWireless obtains 5 hours of technical support whose money value is $50. Similarly, Court Housing has two community members who share their access points, with estimated money value of $100 and received two units of hardware donation of $50 value. Column six represents the money value, as estimated by respondents, of the OSS developed to the network.

Powell (2006) calls networks that depend on the contributions of volunteers *a network of aid*. However, we view CWNs as *value networks* composed of social and technical resources contributed by the community. They also generate social, economic and technical outputs for the community. In general, a value network is defined as a group of people who work together via relationships to create public goods or economic value (Allee 2008). We modeled community contributions in a bipartite graph: G = (U, E), where U = (V U R) where V and R are disjoint sets of vertices (nodes). In other words, there is no link either between any pair of nodes with the set V or the set R. The set V represents the investigated CWNs and the set R depicts the types of contributors represented by their contributions. The set E depicts the ties between V and R. A tie is an ordered pair of nodes (v_i, r_j). These ties represent different forms of community contributions. Each edge has a nonnegative capacity or weight W for all edges (v_i, r_j) $\subset$ E, as shown in Table 1 and Figure 1. If there is no edge between two nodes v_i and r_j or the weight w (v_i, r_j) = 0, then the group of contributors r_j do not support the network v_i. Figure 1 depicts the two sets described in our model: a set of CWNs (the red nodes) and a set of community contributions (the green nodes). The size |R| of the set of contributions is 6. The set R represents the inputs, or the dollar value, of community members, discussed earlier, which include money donation, time volunteered, sharing access points, developed software for the system, and provided technical support. The size |V| of the CWNs set is 16 networks. In this model, the set V represents the sinks, or CWNs, and the set R represents the sources of values or set of contributors. Clearly, the rows, in Table 1, represent the sinks and the columns represent the sources of contributions. To illustrate more, Figure 2 demonstrates NYCwireless as a graph of a super sink and three sources of value.

One of the problems with respect to CWNs is finding efficient ways to summarize and visualize data about the transactions between their actors. Figure 1 depicts the investigated CWNs-by-contributions network. Visualizing such collective projects may uncover some of the hidden information about the interactions between their components. For instance, Figure 1 shows the “goingtogetherness” or “correspondence” of types of contributions, which represent contributors, and associated CWNs. This visualization depicts bundles of CWNs-contributions as clusters in the joint space. For instance, the SeattleWireless, Jawug, NYCwireless, Keur Sedaro, Digital el Paso, Cstle Square WiFi, Champaign-Urbana, and Pretoria Wireless are located close to each other. This togetherness indicates the similarity between these two groups of networks. We also visualized the tangible and intangible resources of these networks in forms of negotiable values. Figure 1 shows that hardware donation (HD) is located far away from the other types of contributions. The other five facets of contributions are located close to each other. We will provide more quantitative analysis to such togetherness in the following sections.

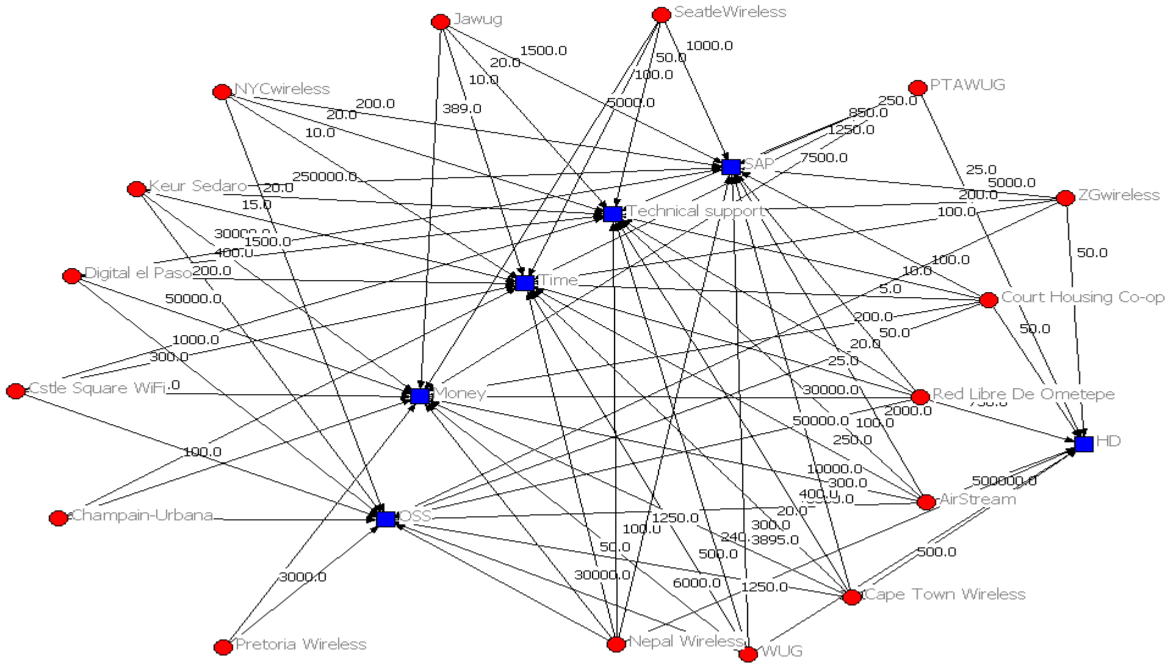

Figure 1. A Graph model for the CWNs-contributors

Figure 2 shows the NYCwireless as a super sink with three sources of values which are shared access points, technical support, and time. It receives weekly volunteered hours of $10 and $20 dollars of technical support and it has 200 dollars worth of shared access points between community members. It does not receive hardware donations, money donations, or free OSS form the community.

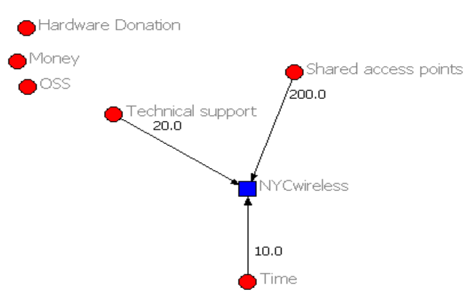

Figure 2. The NYCwireless as a graph of a super sink and three sources of value

Although we provided monetary values for these facets of contributions in this study, this is not meant to measure the real value of the infrastructure. Instead, we used it only for modeling and analytical purposes in order to help researchers and practitioners to apply our method in their investigations. In other words, the main purpose is to provide a new approach to quantify, map and measure the assets of these networks or the community contributions used to build them. It is important to measure these resources so that network managers can manage them. We can also visualize how the wireless nodes are geographically distributed and to what extent these networks are embedded in their communities. Using this approach would be more useful for an in-depth case study that focuses on one, or few, network to have a clearer understanding and a thorough estimation of the resources and assets of this specific network.

5. EMPRICAL ANALYSIS

The proposed graph theoretic model represents a valuable quantitative tool to address key issues related to the resources of CWNs. Following is an empirical analysis of community contributions with the help of this model.

5.1 A comparative study of CWNs

In this experiment we used the developed model to compare different CWNs based on the type and value of community contributions. In particular, we used the similarity function of the UCINET software to compare these networks using the sum of the weights, or the capacity, of their incoming edges or *in* (E). The similarity function measures to what extent two CWNs are similar in this regard. Table 2 shows the similarity between the investigated networks. A similarity of 1 means the two networks are identical (we compare the networks to themselves), and -1 means they are totally opposite to each other in terms of types of involved actors and their contributions. The similarity between the Court Housing and SeattleWireless networks, 0.94, means they are very similar to each other based on the types and value of community contributions. A high dissimilarity between two networks may indicate a good opportunity of collaboration between them. They could exchange knowledge, expertise or OSS. For instance, there are collaboration opportunities between the Champian-Urbana and Cape Town networks, as the similarity between them is -.92. We can also compare the set of contributions to each other using the same approach, and this one of our future work.

1	Court I	Seatle	Champ	AirStr	PTAW	Keur S	Preto	Cstle	WUG	Cape T	Nepal	Red Li	Jawug	NYCw	ZGwir	el Pas
Court	1.00	0.94	-0.55	-0.14	0.81	0.30	0.88	0.88	0.87	0.89	0.90	0.88	0.42	0.12	0.16	0.89
Seatle	0.94	1.00	-0.26	-0.24	0.96	0.06	0.98	0.98	0.98	0.97	0.98	0.31	0.25	-0.11	-0.08	0.99
Champ	-0.55	-0.26	1.00	-0.33	0.78	-0.33	0.00	-0.04	0.80	-0.92	-0.60	-0.35	-0.33	-0.33	-0.34	-0.32
AirStre	-0.14	-0.24	-0.33	1.00	-0.26	-0.29	-0.23	-0.24	-0.28	-0.16	-0.21	-0.27	-0.26	-0.30	-0.26	-0.25
PTAW	0.81	0.96	0.78	-0.26	1.00	-0.19	0.99	0.99	0.99	0.97	0.98	0.29	0.02	-0.35	-0.33	0.99
Keur S	0.30	0.06	-0.33	-0.29	-0.19	1.00	-0.13	-0.14	-0.13	-0.13	-0.11	-0.14	0.99	0.98	0.99	-0.11
Pretor	0.88	0.98	0.00	-0.23	0.99	-0.13	1.00	1.00	1.00	0.99	1.00	1.00	0.00	-0.30	-0.27	1.00
Cstle S	0.88	0.98	-0.04	-0.24	0.99	-0.14	1.00	1.00	1.00	0.99	1.00	1.00	0.00	-0.30	-0.28	1.00
WUG	0.87	0.98	0.80	-0.28	0.99	-0.13	1.00	1.00	1.00	0.98	0.99	1.00	0.01	-0.29	-0.26	1.00
Cape T	0.89	0.97	-0.92	-0.16	0.97	-0.13	0.99	0.99	0.98	1.00	1.00	1.00	0.00	-0.30	-0.27	0.99
Nepal	0.90	0.98	-0.60	-0.21	0.98	-0.11	1.00	1.00	0.99	1.00	1.00	1.00	0.03	-0.27	-0.25	1.00
Red Li	0.88	0.31	-0.35	-0.27	0.29	-0.14	1.00	1.00	1.00	1.00	1.00	1.00	-0.22	-0.31	-0.28	1.00
Jawug	0.42	0.25	-0.33	-0.26	0.02	0.99	0.00	0.00	0.01	0.00	0.03	-0.22	1.00	0.95	0.96	0.03
NYCwi	0.12	-0.11	-0.33	-0.30	-0.35	0.98	-0.30	-0.30	-0.29	-0.30	-0.27	-0.31	0.95	1.00	1.00	-0.27
ZGwir	0.16	-0.08	-0.34	-0.26	-0.33	0.99	-0.27	-0.28	-0.26	-0.27	-0.25	-0.28	0.96	1.00	1.00	-0.25
Digita	0.89	0.99	-0.32	-0.25	0.99	-0.11	1.00	1.00	1.00	0.99	1.00	1.00	0.03	-0.27	-0.25	1.00

Table 2. The similarity between

Another way to compare the similarity between CWNs is using the sum of the weights of the outgoing edges (or *out* (E)). The set of *out* (E) could be used to depict the number of nodes the network has, the number of users it serves or the opportunity cost of its services or value offerings. These potential measures will be addressed thoroughly when we study the outcomes (e.g., accruing social capital, generating human capital, and improving the business environment, achieving digital inclusion). In other words, we will address the dual version of this phenomenon which is considering CWNs as super sources of a pool of added values which feed, or benefit, multiple sinks (e.g., local community, developing organizations, municipalities, technology vendors), or subgroups of stakeholders of CWNs.

We can also use graph concepts to identify the maximum size of the CWNs-by-contributions network. This is a classical problem in graph theory known of *the maximal complete bipartite graph* or the maximal bicliques (Li, Sim, Liu, and Wong 2008). In our case, this graph should include all types of contributions or inputs.

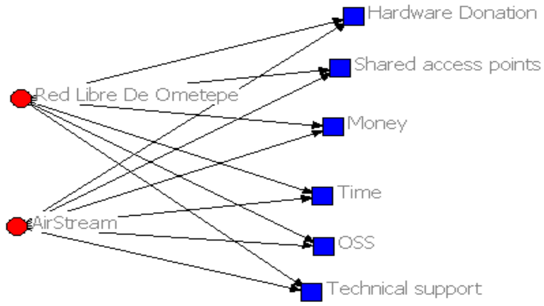

Figure 3. a complete bipartite graph of size $k_{2,6}$

Figure 2 shows that the maximum complete bipartite graph, for the investigated networks, is of size k2,6. It includes two networks: Airstream and Red Libre De Ometepe. Both have affiliations with all the investigated set of contributors. The question arises here is: how can we increase the size of this graph? In other words, how can we enable other networks to affiliate with all possible segments of contributors and engage the community at large?

5.2. Classifying CWNs

The purpose of this experiment is to partition, or group, CWNs-by-contributions into classes based on the density of community contributions. Specifically, we identified CWNs which have high-density of contributions and presented them as close as possible to each other in one block called "the core." We also obtained another set of CWNs which have very low-density of contributions in one group, called "periphery." This approach is called "core-periphery" analysis (Hanneman and Riddle 2005). Others call it "Blockmodel," through which the cells of the data matrix are sorted such that rows and columns that belong to the same class are organized close to each other (Borgatti 2008). We applied this type of analysis to the collected data to obtain an ideal image of high-density and low-density groups along the main diagonal. This approach uses the concept of graph density to classify CWNs-by-contributions. In particular, we partitioned the columns (types of contributions) and the rows (CWNs) into four groups based on the density of contribution for each group. In a directed graph with weighted edges, the term graph density refers to the average contribution of each group or partition. Table 3 shows that the bottom right block has the highest density, 26400.5 dollars, of contributions and the upper right block has the lowest density of contribution which is 283.6 dollars.

Starting fitness: 0.164
Final fitness: 0.179
Correlation to ideal: 0.179

Blocked Adjacency Matrix

		4 SAP	2 Money	6 OSS	1 Time	5 HD	3 Techni
9	WUG	300	6000		500	25	240
6	Keur Sedaro	250000	30000		15		20
11	Nepal Wireless	1250	30000		50	1250	100
12	Red Libre De Ometepe	50	30000	50000	25	750	20
5	PTAWUG	250	7500		1250	25	850
8	Cstle Square WiFi		60000		300		1000
15	ZGwireless	5000			100	50	200
16	Digital el Paso	1500	50000		200		400
13	Jawug	1500	389		10		20
2	SeatleWireless	1000	5000		100		50
3	Champain-Urbana				100		
10	Cape Town Wireless	300	3895		20	500	400
1	Court Housing Co-op	100	200		5	50	10
14	NYCwireless	200			10		20
7	Pretoria Wireless		3000				
4	AirStream	2000	10000	10000	250	500000	100

Density matrix

	1	2
1	20143.809	283.654
2	1510.263	26400.525

Table 3. Partitioning CWNs into groups

A deep look at these blocks shows that the networks in the upper half (e.g. WUG, Keur Sedaro, etc.) have more shared access points, money donations and OSS. They also obtain less volunteerism of time, hardware donations, and free technical support from their communities. On the contrary, the networks in the lower half (e.g. SeattleWireless, Champaign-Urbana, etc.) have less sharing access points, money donations and OSS. They also receive more volunteerism of time, hardware donations, and technical support. The question is: why these two groups are different in terms of types and amounts of contributions they receive. We hypothesize that these different patterns between these groups could be due to the differences (e.g. social values, average income, education, etc.) between the contributors across these networks. We can also compare the density of each group to the density of the whole graph which is 12719.6 dollars. This density could be used to measure the level of community engagement in the investigated networks. Yet, we would like to emphasize that these facets of contributions are dynamic in terms of the number of contributors and the type of their inputs. This is because of the loose structure and nonprofit status of these networks, similar to other collectivities.

6. SIGNIFICANCE OF RESEARCH

Through the Internet, users share data, exchange massages and collaborate on research, and develop OSS (Lesser, Fontaine and Slusher 2000). In this study, we show how they build and share telecommunication infrastructures. In particular, we use graph theoretic approach to propose fresh perspective for understanding the role of communities in the development of their wireless infrastructures. In particular, we modeled, measured and analyzed the contributions of community members in a quantitative and compact manner. To measure community contributions in these collective projects, we construct the variables of OSS, money donations, technical expertise, voluntary work, node-sharing, and hardware donations. Identifying, mapping, measuring and evaluating these resources are important for a successful CWN endeavor. We also distinguish contributions of technical processes (e.g. developing OSS, providing technical support) from unskilled manpower. This would be useful if we study the role of CWNs in building technical expertise or human capital. Furthermore, we convert them into marketable values, using their opportunity cost, to help us aggregate them and measure the market value of these collective projects.

This study provides policy makers with important insights into CWNs as a potential solution for the digital inequality problem. The used analytical approach could be used to assess the socioeconomic benefits of such collective projects. Measuring such benefits may help researchers to obtain new insights into how to engage more participants. In particular, it may help community leaders to convince governments, OSS groups, students and developing agencies to contribute to this movement. The participation of government entities, for instance, may take different forms such as providing funds, deregulating the necessary spectrum, and/or providing the legal rights of communities and nonprofit organizations to collectively build, own, and run such telecommunication infrastructures. We also hope that the proposed model would expand the problem-solving abilities of practitioners when they use it to visualize, map, measure and manage the resources and outcomes of CWNs.

For academicians, our study provides an elegant analytical approach and a rich set of conceptual insights to guide current and future research on CWNs and similar collectivities such OSS groups, MySpace, Wikipeda, Facebook and other online forums and collaboration groups. In particular, our approach in treating CWNs as value networks is necessary to capture the complexity of relationships and transactions between their actors. Proposing such an approach, at this embryonic stage, is important in order to advance this intellectual stream. Another scientific contribution of this paper is providing an example of how to treat 2-mode network data and how to assess intangibles using their opportunity costs.

We believe that this perspective of treating the resources and assets of CWNs is illuminating but incomplete. Its main limitation is excluding important facets of community contributions such as boosting the publicity and awareness of the project. Another limitation is assuming that both CWNs and contributors are disjoint sets. In other words, we assumed that there are no relationships between individual CWNs and that groups of contributors do not intermix; however, this is not the case in reality. For example, volunteers may donate money, provide technical support, and/or develop software for the system. We isolate these inputs in order to distinguish financial contributions from nonfinancial contributions and cognitive contributions (e.g., technological processes) from non-cognitive contributions (e.g. manpower). In addition, CWNs collaborate with each other in OSS development (e.g. their annual summit). We assume that these two sets are disjoint only for analytical purposes. Another important observation is that the agents of CWNs are spatially distributed and their cooperation may occur virtually or over time. Furthermore, the used data, Table 1, is correct only at the time of data collection, which is June of 2008. These networks are dynamic and their lack of commitments of participants. However, the adopted analytical approach should be useful in helping researchers resolve a number of critical issues related to CWNs. There is also methodological issue as the used SNA approach is limited only to small networks where we have confidence in the reliability of our observations, according to Hanneman and Riddle (2005).

It would be interesting if future work relates contributions of actors to their attributes such as their size, social values, income, age, gender, diversity, social cohesion and education. This may help answer questions such as why there is so much voluntary participation or money donation in specific networks compared to others. Another potential topic is focusing on one or few CWNs and study the one-mode, or micro, relationships (e.g. benefits, contributions, reciprocation, influence, solidarity, trust) between their actors. For instance, focusing on one network would help researchers to visualize and classify the contributors, beneficiaries, and isolates in a specific community. Our future work will focus on the dual version of the relationship between CWNs and their actors. In particular, we will investigate how CWNs, as macro-structures, create values for participants (e.g., volunteers, OSS developers, underserved communities) as micro-structures. We will use the adopted analytical approach to treat CWNs as sources of values. In particular, we will provide a careful analysis of the role of these networks in creating social capital and human capital.

7. CONCLUSIONS

This study presents a new direction in understanding the role of communities in developing their CWNs. In particular, In particular, it provides new insights into the role of communities, as macrostructures, in developing CWNs, as microstructures. We used graph concepts to model community contributions in the development of their wireless infrastructures. The proposed model is used to visualize, classify, and compare CWNs. The originality of our work lies in providing a generic approach to help practitioners and academicians to treat CWNs as value networks and systems of transactions. We considered both the tangible and intangible resources shared, mobilized or reproduced to build these networks. This study is an important step towards advancing this area as a research stream. It fills a gap between theory and practice for community activists, developing agencies, and researchers as it describes CWNs as systems of exchange. The phenomenal growth of this new form of collective actions is expected to completely revolutionize the telecommunication landscape and provide momentum to the digital paradigm. However, they need the attention of governments, developing and outreach organizations, technology vendors, students and researchers.

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