Communications and Information Existing Models Paper for 2019 DUET Megacity Project

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1 Introduction

The Communications and Information team of the DUET Megacities project is tasked with modeling the communications and information systems of Africa, Europe, and Asia. In this paper we present three models of various aspects of these systems that we find particularly relevant.

The Wyner models is a process used to analyze large user based cellular networks due to its "simplicity and analytical tractability" [14]. The model's key features include using fixed user locations to understand deterministic and homogeneous interference intensities. This can be used in providing a wealth of nodes for connectivity through communication and information networks in urban environments.

And the Poisson point process and Poisson cluster process models are also models that have been developed to analyze cell tower or base station distribution in wireless networks and determine coverage probability. Some [9] have found these models to be significant improvements over models like the hexagon grid traditionally used to calculate coverage probabilities and even, in some cases, to determine how to deploy different kinds of base stations.

Dean Barnlund's transactional communication model is a design based on a continuous communication feedback loop between sender and receiver that accounts for whether or not a message is understood. This model can be used to analyze social network communication nodes and social media virtual relationships in the development of megacities and their governance. Sociocultural communication network nodes indicate hotspots that have the potential to be disrupted by military activity and should be analyzed in addition to geometric analysis that include physical communication lines such as buildings, roads, and cellphone towers.

2 Dean C. Barnlund Transactional Communication Model

2.1 Model Introduction

The inspiration in choosing to analyze this model comes from the importance of social networks in the development of urban areas Barnlunds transactional communication model helps analyze this communication feedback loop. Dean Barnlund describes communication as the process of creating meaning, which includes current experiences and emerging needs; he argues that messages may be generated from the outside, but meaning is generated from within [3]. Barnlund states that communication ceases when meanings are adequate and is initiated when new meanings are required [3]. The Transactional Communication Model has five principles: (1) communication is a process in which the sender, message, and receiver do not remain constant throughout an act of communication (2) communication is not a linear process but a circular process (3) communication is a complex process (4) communication is irreversible and unrepeatable (5) communication involves the total personality which influences its effects on behavior [3]. The transaction model of communication accounts for a feedback loop and cultural context such as race, gender, nationality, sexual orientation, class, and ability that enhance or impede communication [8]. This model consists of continuous, multi-layered feedback system that consists of public cues, private cues, and behavioral cues [5]. Public cues (Cpu) are defined as the physical, environmental, artificial, natural, or man-made. Private cues (Cpr) are private objects of orientation which includes a persons senses and can be verbal or non-verbal. Behavior cues and either be verbal (Cbehv) or non-verbal as well (Cbehnv) [5]. Arrows are used to show the direction of the message sent and where the receiver gives feedback. Jagged lines (VVVV) shows the availability of cues [5].

Figure 1: Barnlund Transactional Model of Communication [5]

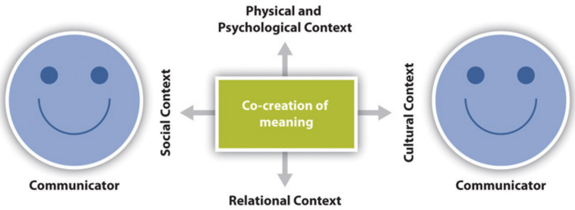
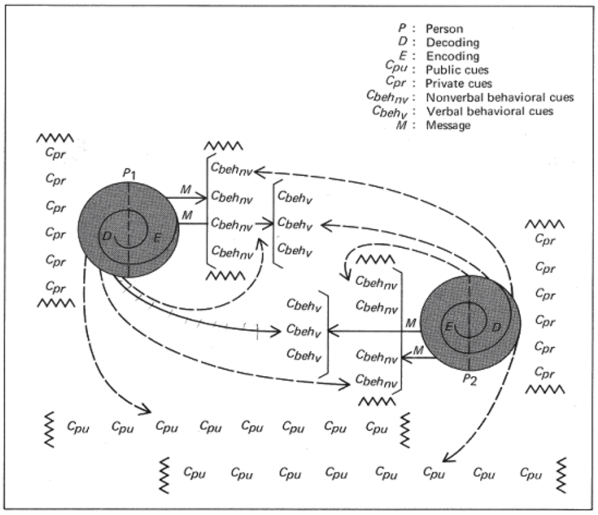


Figure 2: Barnlund Transactional Model of Communication [8]



2.2 Interpretation and Megacities Implications: Africa

Previous communication models, such as Shannon and Weaver, were linear in design and viewed communication as a one-way process. Linear communication models focused on the sender, and although they accounted for whether or not the message was received, these models did not account for whether or not the message was understood. Barnlunds model takes into account that actors are simultaneously engaging in the receiving and sending of messages. The Barnlund transactional communication model is more applicable to todays society with the growing importance of social media and microblogs that aid in the formation of social networks and have become primary platforms for communication. Critical nodes within social network communication are each person or organization and web pages in the World Wide Web [6]. Major impacts of changes to communication within social networks affects interpersonal social ties, especially those that are weaker or absent. Weak ties play an important role in binding strong ties together, and are crucial for bridging two nodes together [6]. Barnlunds transactional communication model can be used to interpret the effectiveness of communication between nodes, especially the feedback loop between organizations, especially governmental agencies, and the populous in emerging megacities. This model can also effectively analyze how social media affects communication and the interpretation of messages between two nodes and the development of social networks. Major impacts to social media communication platforms can also affect relationships between critical nodes. Advantages of Barnlunds transactional model of communication are that the model shows a shared field experience of the sender and receiver and includes simultaneous message sending, noise and feedback. Disadvantages of this model is that the sender and receiver must understand the codes sent by the other [5].

Thirty-nine percent of the global population is expected to live in Africa and more than eighty percent is expected to reside in urban areas which makes communication within social networks an important aspect of urban life to analyze to avoid disruptions as African cities transition to knowledge-based civilizations" [10]. As African megacities develop, social networks provide opportunities for governing change through partnerships and collaborations that govern change with the aid of establishing effective communication feedback loops. Through these communication feedback loops within growing social networks in megacities, partnerships form between the public and private sector with academia, civil society, citizens, and social media participants playing a role in governance within megacities. Communication within urban social networks provides multi-faceted governance and engagement that help to provide funding, ensure sustainability initiatives, monitor progress, and develop new technologies that allow citizens to challenge and shape public opinion and contribute to the governing of megacities [10]. Smart devices are becoming the communication mode of choice in urban, African cities which has created information-rich cities because of the instant sharing and public communication. The study of these information-rich urban areas can allow for spatial clusters to be identified and categorized as either entertainment, politics, and military and the formation or re-formation of social networks. The creation of social networks allows for communication to facilitate the mobilization of citizens in response to ongoing events [7]. These social clusters in communication networks represent potential impacts to communication that should be avoided in order to maintain the integrity of the development of megacities in Africa and to maintain the feedback loop within megacities to ensure proper community governance. Megacities should be analyzed through forms of mass communication and social networks in addition to geometrical spaces such as road networks, buildings, and cellphone towers because sociocultural meanings are applied to locations and identify urban sociocultural hotspots; social networks along with the virtual interaction capabilities of social media can lead to connected communities that span across distances, connecting distant nodes in other communities and expanding the footprint of area of operations [7].

3 Poisson Point Process and Poisson Clustering Process Model of Base Station Locations

3.1 Model Introduction

The inspiration for choosing to analyze this model comes from "Stochastic geometry based models for modeling cellular networks in urban areas" by Chia-Han Lee, Cheng-Yu Shih, and Yu-Sheng Chen [9]. In this paper, the authors use OpenCellID, "the worlds largest Open Database of Cell Towers" [11], to analyze the accuracy in practice of various models for determining base station locations. They analyze a hexagonal grid model, a Poisson Point Process model, and Poisson Clustering Process models applied to cities in the Americas, Africa, Europe, Australia and Asia. Like the authors of [1], they conclude that Poisson Point Processes are indeed more accurate than the hexagonal grid model. But while [1] finds that Poisson Point Process models determine a lower bound on coverage probability, the authors of this paper find that, like the hexagonal grid model, Poisson Point Process models only determine an upper bound on coverage probability. The authors also introduce Poisson Cluster Process models, and demonstrate that these accurately predict the geographic distribution of base stations in cities.

The traditional approach most commonly used by communications engineers has been to divide the whole area to be covered into a lattice of hexagons (or, more simply, squares) and place a cell tower in the center of each hexagon (or square) [1]. But as Andrew et al. note [1], this model "is highly idealized and may be increasingly inaccurate for the heterogeneous and ad hoc deployments common in urban and suburban areas, where cell radii vary considerably due to differences in transmission power, tower height, and user density" (p. 3). This is illustrated, for example, by "picocells . . . often inserted into an existing cellular network in the vicinity of high-traffic areas, and short-range femtocells . . . scattered in a haphazard manner throughout a centrally planned cellular network" [1]. Moreover, though worst-case scenarios for coverage probability (when users are located at the corners of the hexagons or squares) are possible to calculate, Andrew et al. [1] state that no such computations can easily be made when user locations are assumed to be random – in this case "complex time-consuming simulations" are used. So an alternative that is more accurate in todays urban environment than the hexagonal grid model, and that enables easier coverage probability computations, seems to be necessary.

An alternative proposed for modeling coverage probabilities is Poisson Point Processes. In this approach, a density λ (which in some cases may not be constant) is chosen and the number of base stations in any closed and bounded set A on the map is thought of as Poisson distributed with mean $\lambda|A|$, where $|A|$ denotes the area of A. That is, if $N(A)$ is the number of base stations in A, then $\mathbb{P}(N(A) = k) = \frac{e^{-\lambda|A|}(\lambda|A|)^k}{k!}$. The authors of [9] and [1] agree that modeling base station locations this way allows for more accurate calculations of coverage probabilities and represents an improvement over the hexagonal grid approach. The authors of [9] apply this Poisson Point Process method to calculate coverage probabilities in cities around the world based on data from OpenCellID.

However, the authors of [9] note that because real-life deployments of base stations, while somewhat haphazard, tend to cluster around places of high user activity. They therefore cite [2] to introduce a Poisson cluster process, which "is formed by taking a Poisson process Φ of parent points with density λ_p and replacing each point $x \in \Phi$ by a random cluster Z_x which is a finite point process [that is, a random point process in a finite space]. The superposition of all clusters yields the Poisson cluster process $Y = \cup_{x\in\Phi} Z_x$. The authors of [9] specifically consider the Matern cluster process model, in which "the number of nodes in a cluster is Poisson distributed with mean $\bar{c}$ and the nodes are uniformly distributed within a circular region with radius R centered at the location of the parent node the cluster replace[s]. They also consider a "type II Matern hard-core process, in which points from a parent Poisson point process with density λ_d are not replaced by clusters but instead deleted if they are within distance d of another point - d is referred to as the "hard-core distance [9]. The authors of [9] seem to imply that this yields a new Poisson point process with density $\lambda = \frac{1-e^{-\lambda_p \pi d^2}}{\pi d^2}$, though they do not say explicitly that the resulting point process is a *Poisson* point process.

A last model the authors of [9] mention is called a Geyer saturation process, which they use "for fitting the real data. Because we are most interested in describing real communications networks, Geyer saturation processes might actually be even more useful for us than the models previously described. But this requires more investigation, because the authors of [9] do not explain the Geyer saturation process – they only cite [13] and [12] for reference.

Figure 3: A Google Maps image Taipei City, Taiwan, with its base stations (labeled as blue triangles). Source: [9].

3.2 Interpretation and Megacities Implications: Asia

The hexagonal grid, Poisson point process, Poisson cluster process, and Geyer saturation process models provide rich tools to model the communications networks of Asian megacities. Though these tools were developed to model wireless cellular coverage specifically, perhaps they could also be applied fruitfully to

Figure 4: Distribution of base stations in Tokyo. 25% of the population lives in the red rectangle, 1% of the population in the smaller green rectangle. Source: [9].

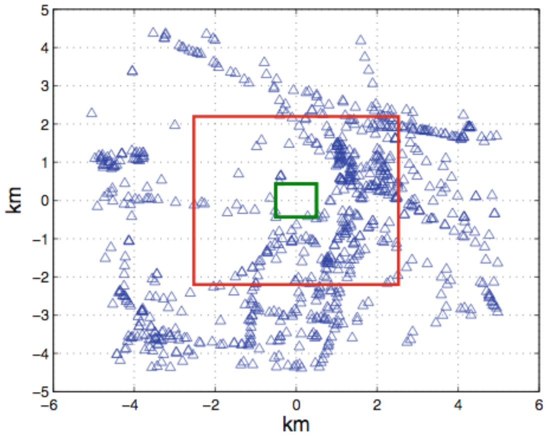
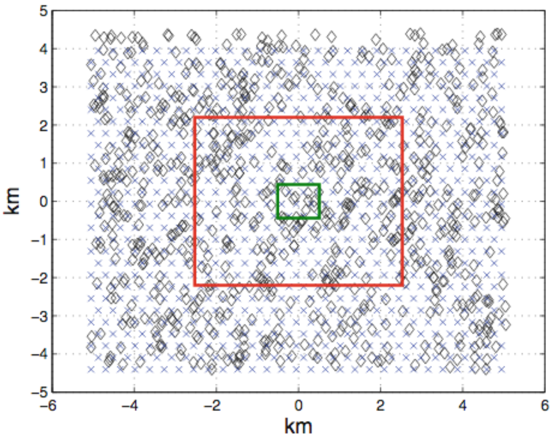


Figure 5: Two models of the distribution of base stations in Tokyo. Those generated by hexagonal grid method are represented as triangles and those generated by the Poisson point process method as diamonds. Again, 25% of the population lives in the red rectangle, 1% of the population in the smaller green rectangle. Source: [9].



or used to understand other components of ICT, such as television and radio broadcast, wired phonelines and internet connections, wireless internet connections, social networks, and more.

Some of the *information themes* involved in such a more general system are (successful or failed) connectivity, speed of propagation of information, inaccessibility, and network design. The entire system in some sense represents a *flowprocess*: the flow of information. People exchange information using ICT. It also might be interpreted as a flow of connectivity. A cellphone users phone determines the base station closest or best suited for its use even as the user changes location, allowing successful connections to be made despite system disturbances.

The exist *causal relationships* between the number of people living in a given area and the distribution of cell towers or base stations in that area. In general, the concentration of people and the concentration of base stations (as well as the variety of base stations, ranging from picocells to femtocells and others) tend to be positively correlated. This could reduce the impact of failures of base stations in the wireless network as compared to failures of certain links in wired networks.

Various cell towers are certainly *interdependent* in that their presence together increases a users coverage probability. But aside from being positively interdependent they are also negatively interdependent, in the sense that sometimes they can interfere with each others signals, thereby (somewhat ironically) decreasing a users cell coverage probability.

The main *actors* in this system are certainly the cell towers or base stations themselves, the companies building them, and the users using them. These actors exist in complex, interdependent dances of feedback and mutual influence. The companies decide where to put base stations based on the needs of the users, whose location plays a role in the success of the base stations and in whether the company building the base stations will ultimately be lauded or condemned.

Because base stations act locally, the system-wide *impact of changes* to the system does not seem to be large. That said, maybe there is something about this system we have not yet considered. Is any sort of central control necessary to keep it running smoothly? If so, where is the central control exerted from, and how is it administered? Might not such a place from which central control is exerted or a a place from which this control is administered be a *critical node* of this system?

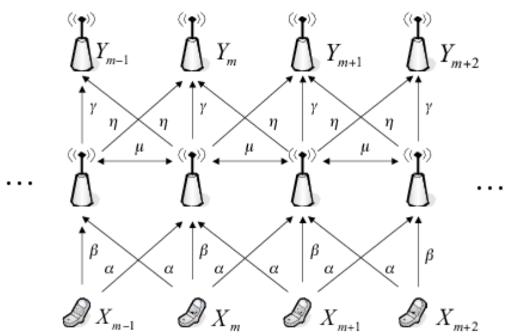
Poisson point processes, and even more so Poisson cluster processes, are very well-suited to modeling cellular coverage in Asia. This is because many cities of Asia are very densely populated (and may become more so) and have (or have) very heterogeneous networks. Thus, the randomness inherent in Poisson point processes, Poisson cluster processes, and probably also Geyer saturation processes models the situation fairly accurately.

That said, there seem to be some *weaknesses* in these models. While the authors of [9] show them to be fairly accurate in predicted Base Station location and coverage probability, one wonders whether the fact that service providers deliberately choose where to put cell towers or base stations means that there is a better approach to determining the geographical layout and systemic features of a wireless network in a given city. Moreover, while these models are fairly “tractable (that is, easy to make computations with), they are still often fairly “intractable (difficult to make computations with. We should keep these weaknesses in mind as we continue our analysis of these models.

Yet these models also have many strengths. The authors of [9] have shown their predictive power to be very powerful across many different geographies, a boon especially for a continent as a large and diverse as Asia. Moreover, while they only relate to a specific area of ICT and the broader communications system, they provide deep insight into this particular aspect of it. They may also help us develop similar models for other aspects of the ICT system.

3.3 Wyner Model

Figure 6: Wyner Model With Dedicated Relays: Showcasing the possibilities of its broad interconnected networks [16]



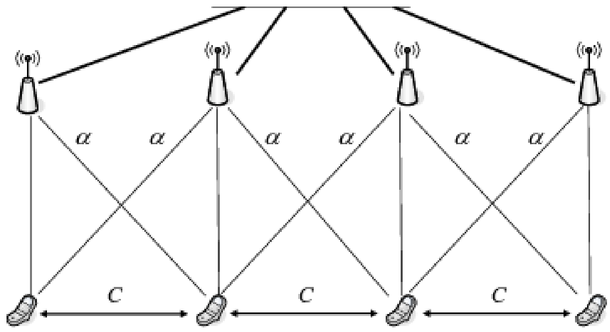
Grid-based models often cannot handle multicell networks analytically so Wyners Model can be used to simplify the methods in which researchers model and analyze these networks (Figure 6). Analytical and simplistic models such as these are in limited within Cellular communication networks. Some of Wyners

Model key features included “fixed user locations and the deterministic and homogeneous interference intensity” [14]. This model was tested by Jiaming Xu, Jun Zhang, and Jeffrey G. Andrews in “On the Accuracy of the Wyner Model in Cellular Networks [14] and proven to be accurate within systems harboring a large number of simultaneous users such as a CDMA system, during uplink transmissions.

3.4 Interpretation and Megacities Implications: Europe

Using this model, researchers will be able to cover a wider array of communication networks with a system that can keep up with the large amounts of data. This is useful in conducting simplified analytical action in order to advance processes and remaining furtive within urban environments. One weakness within this model would be the downlink transmissions. In contrast to the accuracy of the uplink transmissions, the downlinks are less accurate since this flow process depends largely on a user location (Figure 7). [14]. However, the average results of this model are deemed acceptable if interference parameters are coordinated for their environment. It is necessary to note that the Wyner models processing capacity can be both limited or expanded varying by the environment its used in. According to “Capillary Networks: A Novel Networking Paradigm for Urban Environments, by Isabelle Aug-Blum, Khaled Boussetta, Herv Rivano, Razvan Stanica, and Fabrice Valois, the European Union is rapidly fostering public initiatives to find breakthroughs within “technologies for automatic and efficient management through the creation of interconnected smart cities [15]. This usage of capillary network interfaces provides a wealth of nodes for connectivity through cellular networks, multi-hop wireless, and even mature technologies. These types of multifarious networks being applied by smart cities create critical nodes of flexibility within European networks. Due to the diversifying of European urban environments through the upgrade of technology, the Wyner model becomes a viable and reliable option within communications and Information.

Figure 7: Wyner Model With Limited-Capacity Conferencing Channels: Showcasing limiting factors within this model. [16]



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