Community-Level Access Divides: A Refugee Camp Case Study

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ABSTRACT

Despite the appearance of uniform availability of mobile services, in many locales granular network analyses reveal the persistence of physical access divides. It stands to reason these divides, similar to those at larger scales, are also reflections of community-level social and economic divides.

In this research, we examine community-level physical access divides in the context of a Syrian refugee camp. The investigation combines detailed network and organizational analyses to characterize the divides and identify factors influencing their creation and potential solutions. Our findings show that even in the limited confines of a refugee camp, coverage patterns and bandwidth availability differ significantly both within and between the networks of three mobile cellular carriers. These patterns, together with the overall configuration of network infrastructure, demonstrate three community level divides: an inter-carrier congestion divide, a spatial distribution divide, and an inter-network divide. We identify a number of linkages between these divides and the social, organizational and humanitarian context of the camp. Building on these analyses, we provide recommendations to ameliorate these divides for both residents and camp management.

CCS Concepts

•**Networks** → **Wireless access points, base stations and infrastructure; Network measurement;** •**Social and professional topics** → *Geographic characteristics;*

Keywords

Cellular Networks, Cellular Measurement, Network Congestion, Community Access Divides, Refugee Camp, Syrian Refugees

1. INTRODUCTION

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Recently, much of the focus of social science research on digital divides has shifted from their physical basis to those concerned with devices [18] or differences in usage [28]. However, as recognized by computer scientists [5] and practitioners alike, there are still many places, particularly on smaller scales (e.g. rural communities, urban canyons), and circumstances (e.g. disasters) where physical access is problematic.

Unfortunately, users are typically made aware of these coverage gaps through poor service, characterized by little or no signal, dropped calls or slow data speeds. Some see a solution in consumers armed with objective information on networks' effective coverage and bandwidth, agitating for better service. In the U.S., efforts to measure fixed and mobile broadband coverage are under way [7]. However, to date, these efforts have long time scales and aim to provide data over large geographic scales. Since consumers primarily are concerned with network usage within their community, as yet it is unclear whether and how these large scale data sets will empower consumers, particularly at the community level.

A community level perspective encourages a holistic view of the network environment, one that is more reflective of users' experiences switching between fixed and mobile networks, offered by a variety of providers. Together, these diverse networks and their providers offer more robust coverage than either could offer alone. Understanding the policies and practices of all provider organizations (shops, schools, firms) is critical for assessing the viability of potential solutions to community level divides.

Here we examine community level digital divides in the context of the Za'atari Syrian refugee camp in northern Jordan. Of the 12 million refugees served by the United Nations Refugee Agency (UNHCR), roughly 37% reside in camps [26]. As compared to most, this camp is relatively urban and is served by three mobile carriers. Still, the carriers, together with the camp managers responsible for infrastructure, are failing to meet the demands for bandwidth and connectivity, for refugees and their service providers alike.

Efforts to enhance camp-based information and communications technology (ICT) infrastructure, like that announced by Facebook CEO Mark Zuckerberg in the fall of 2015[1],

[1]http://www.nytimes.com/2015/09/27/world/americas/mark-zuckerbergannounces-project-to-connect-refugee-camps-to-the-internet.html?_r=0

eventually must confront the question of ‘for whom?’ While many might assume such humanitarian efforts would target access for refugees, such projects must consider the sometimes competing needs of refugees and camp management.

Our analysis takes into account these diverse needs and their reflections in network designs and architectures by employing a social informatics frame. Social informatics views ICTs as complex and interconnected sociotechnical networks, premised on the assumption that the social and organizational settings in which ICTs are embedded are in a relationship of mutual shaping [16]. Social informatics research involves normative, analytical, and critical orientations; here we primarily take a normative approach, seeking to influence practice. Yet, elements of the analytic approach, further developing theory, and a critical orientation, which calls into question standard procedures or assumptions, are also found.

Our novel use of detailed community-level cellular network analyses identifies unique divides and their relation to the camp’s social systems of refugee service providers. Service providers offer food, shelter, and clothing, among other services, and include agencies of the host country government, and the mobile network carriers. The technical systems are characterized by the properties of the camp’s wireless and cellular networks as well as the social and technical systems that influence the availability of SIM cards, mobile phones, laptops and desktop equipment in the camp. With this background, our research identifies digital divides in the Za’atari refugee camp in Jordan, explains how these divides emerged, and makes recommendations for future infrastructure development and related policies.

Accordingly, our main research questions are:

- *What are the technical characteristics of the Za’atari camp’s network infrastructure?*
- *What divides, if any, do the infrastructure characteristics reveal?*
- *What organizational policies and practices influence these divides?*
- *Taking into account both the technical and social / organizational findings, what are possible solutions?*

2. RELATED WORK

Social informatics analyses view information technologies as sociotechnical networks, where technologies are not seen as mere tools, but instead as artifacts of a complex set of factors shaping their design, deployment and use. These investigations are often multi-level, taking into account societal, organizational and individual factors in studies of ICT use (see e.g. [21]), as well as viewing networks as complex systems of configurable technologies [23].

To this end, the information infrastructure of the camp is disaggregated into commercial cellular networks, together with the wireline and WiFi networks commissioned and operated by UNHCR. Performance measurement of the three cellular networks in the camp enables us to answer questions such as: is signal strength uniform throughout the camp? Are there differences in the likelihood of high speed (3G) connectivity across the three networks? And are there differences between the networks in the likelihood of immediately obtaining the resources necessary for a voice call, SMS, or data session?

Our measurement of the cellular infrastructure focuses on messages broadcast over the GSM air interface rather than application-level performance. Recent work has illustrated the potential impact that cellular radio state has on end user experience [27, 22, 17]; and how air interface messages can be used to infer cellular user activity [3].

Together, our research contributes to network measurement research, to the scholarship on community-level digital divides, and the nascent scholarship on ICT use by and for refugees. Recent studies, both theoretical and empirical, cover a range of technologies and contexts, including how online mapping technologies might be used to engage refugees in camp activities together with international organizations [25, 30]; how mobile phones could be used to enable refugees to migrate and resolve uncertainties of everyday life [11]; and how computer clubs could be established to foster learning, social networks and integration with local communities [2]. In terms of network measurement scholarship, this work demonstrates how detailed, micro-scale analyses can support research on *community-level* infrastructure. This approach contrasts efforts to measure network performance on a global or nationwide scale, such as the FCC’s Measuring Broadband America [7], and enables us to specifically assess the client-facing infrastructure serving the camp. Our analysis separates performance attributable to local infrastructure from that which is attributable to entities within carriers’ core network hierarchies.

Finally, our research contributes to the digital divide literature in three ways. First, we provide a middle ground for physical access research [29], offering a more granular perspective as compared with those conducted at broader geographic scales [4] or at the level of individual users [10]. Second, we also provide middle ground by highlighting the role of organizations as both potential providers and influencers of network infrastructure, that at the same time are consumers of bandwidth at the community level. As such, our research fills the gap between studies seeking to explain divides based on analyses of government policies at national and sub-national (state, province) levels, as well as those that seek to shed light on policies and norms affecting individuals’ cognitive and social access [29]. Finally, our community level analysis complements the primary scholarship at this level, namely community technology centers. By highlighting the broader technical aspects of access, particularly in the very popular mobile and wireless realms, our research expands notions of community level digital divides.

3. METHODS

Our research is based on data collected from the Za’atari refugee camp. We use multi-method analyses of data gathered through technical signal measurements, together with social observations, surveys, and unstructured interviews with UNHCR Information Management staff and some implementing NGOs during visits in February 2014 and January 2015. Our choice of Za’atari was motivated by several factors, including (1) contacts that enabled access, (2) a reasonable security environment, (3) its proximity to Jordan’s capital, Amman, and (4) its reputation as one of the most technologically advanced refugee camps.

Data collection was conducted in two phases. Informal discussions led to further interactions, generating information with increasing depth and specificity as details of the context were revealed. The first visit by the team leader was conducted in February 2014 with the purpose of gaining access to the camp for the broader research team and conducting interviews and engaging in discussions to understand the camp's ICT infrastructure. During this visit meetings were held with the UNHCR camp manager, the military General in charge of the Directorate for refugee affairs in the Ministry of the Interior, camp security staff and ICT staff in UNHCR's Amman office.

The second visit, with the entire team, was conducted in January 2015, through a permit issued by the Jordanian Ministry of Interior. The interdisciplinary team consisted of three faculty and three doctoral students from disciplines ranging from information science and geography to computer science. During this second visit several studies were carried out, with the findings reported here the combined results of two separate studies, one on infrastructure measurement and a second on infrastructure use. Interviews during the January 2015 visit were held with a variety of NGO managers as well as several UNHCR staff in general camp management, food distribution, and infrastructure management, all working in the camp. As stated in the introduction, our goals were to assess the camp-serving network infrastructure as well as the underlying policies and practices influencing network performance and usage.

3.1 Cellular infrastructure measurement

We characterize the camp-serving infrastructure from two perspectives: the overall ability of the networks to serve individual users and a look at the infrastructure from a geographic standpoint. Our goal was to gather measurements to objectively quantify the cellular coverage in the camp, as prior reports have characterized the camp cellular networks as "unusably slow for most of the day" [20].

We collected cellular measurements in Za'atari over the course of three days in January 2015. Our data collection focused on cellular control messages as well as received signal strength indicator (RSSI). Two researchers carried matching bundles of sensors, each composed of 1 Lenovo laptop, 1 Nuand bladeRF software-defined radio, and 4 Android phones. The number of devices was limited by battery life and the USB power limits of the laptops. We used the software defined radios to collect raw spectrum measurements as well as perform wide-band spectrum sweeps to detect cellular base stations. Each Android phone was equipped with a SIM card for one of the cellular carriers available in the camp. For every carrier at least one phone was configured to prefer 2G data connectivity and one phone was configured to prefer 3G as these are the technologies available in the camp. The phone models were Samsung Galaxy S2, Galaxy Nexus, and Galaxy S4 handsets with radio debug mode enabled. Radio debug mode logs all cellular communications to a computer via USB. We used `xgoldmon`, an open source tool that converts debug logs into easily parsable and human readable packet capture (pcap) files. Each phone recorded all of its own uplink traffic as well as all broadcast traffic sent by cellular base stations. Using the eight Android handsets, we were able to log more than 95,000 cellular control messages. Phones also ran an application that logged latitude and longitude coordinates and cellular network details (e.g. RSSI, cell-ID, and connection state).

3.1.1 Limitations

Systematic dataset collection was limited by the constraints associated with gathering data in an active refugee camp. Data were collected while traversing the camp in UNHCR vehicles, where travel and routes were determined by regular business needs during car trips made for other purposes. For this reason, our data do not include points along the western ring road as during our visit the UNHCR personnel we worked with had no pressing need to visit that location.

3.1.2 Cellular network control messages

We passively observed messages broadcast by cellular base stations defined by the 3GPP Technical Specification 04.08 [1] in order to learn network characteristics from the user perspective. Rather than measuring performance at the application level, we leveraged cellular control messages to gain insight into the radio access layer and the operating state of the cellular provider. This is preferred for our study as we aimed to characterize the capability and capacity of client-facing carrier infrastructure rather than study end-to-end connections. While carriers have full knowledge of the state of the cellular network hierarchy including control traffic, we, on the other hand, measured and characterized the infrastructure from the user perspective and are limited to the control messages that are broadcast over the air interface. Importantly, our message collection techniques are **non-intrusive** and **non-invasive**: all captured messages are broadcast by base stations in plain text on control channels and are intended to be received and processed by all phones associated with a given base station. Importantly, some plain text broadcast messages contain temporary user identification information, which prior has been shown to be mappable to individual user location over extended observation periods [15]. In our work we discard these values as they are not relevant to our study.

4. ZA'ATARI CAMP OVERVIEW

Za'atari is one of four refugee camps in Jordan, and is the oldest and largest. Located in a desert region near the border of Syria and Jordan, it is one of the largest camps in the world. The camp was established when, as the influx of refugees increased, voluntary sheltering of refugees by Jordanian families could no longer absorb the flow. As a result, in July 2012, UNHCR, together with the Jordanian Hashemite Charity Organization (JHCO), opened the camp. Within the first three months the camp was home to 30,000 residents who brought with them $\sim$10,000 mobile phones.

Since then the camp population swelled to 120,000 residents, and now after three years of existence, is stably hosting roughly 80,000 residents in roughly 6 square kilometers. As the camp grew, the Jordanian government became increasingly involved in its operations, particularly as security concerns and the need for educational services increased. Camp growth also required expanding functional boundaries and changes in land use itself. The increasing density of housing in the 'old' part of the camp, led UNHCR to expand housing areas to be places further afield, which were unfortunately distant from many service locations and economic activity in the camp. Also, changes in camp food management processes led to the abandonment of a food distribution location near the camp's entrance in favor of modern grocery stores further from the entrance.

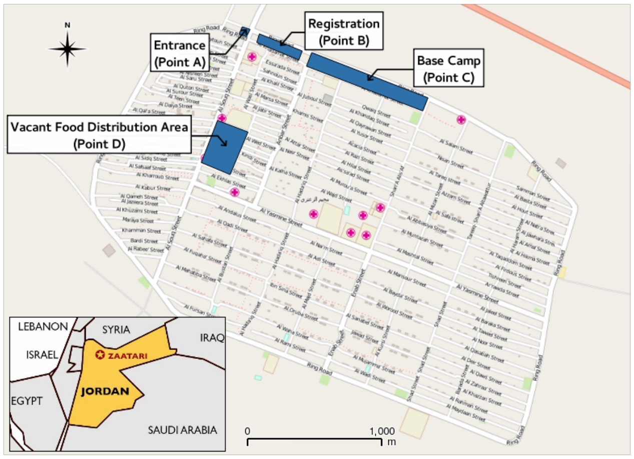

Figure 1: Za'atari camp map.

4.1 Network infrastructure

The infrastructures of the camp are influenced by its physical layout (Figure 1). The camp is a contiguous area with a main gate (Point A) through which access is restricted. In theory, only residents, visitors, and camp staff are allowed to enter. Near the entrance, a fenced off section commonly referred to as 'base camp' (Point C) houses the offices of the international organizations. Due to conflicts between camp residents and staff, as well as to protect valuable equipment against theft, base camp is a secure environment. Surrounded by a concrete wall with a barbed wire fence, those entering must show identification documents.

These offices, housed in caravans (similar to metal trailers used in the U.S.), are served by a UNHCR Internet connection. Provided via a microwave network between nearby Mafraq and the camp, the link is terminated in a radio room in base camp. Throughout base camp, Internet access is provided through WiFi to UN as well as non-governmental organizations. A buried fiber cable is used to connect base camp to the adjacent registration area (Point B), where important data, including biometrics, is collected from refugees as they enter the camp for the first time. Hence, base camp embodies a geographic concentration of political power, housing the camp's management, social service organizations and security, upon which the refugees rely for all essentials. With the camp's only fixed network connection, base camp also reflects not only political power in their ability to have this connection (further elaborated in the discussion), but also economic power in that they can afford it.

Outside of base camp, organizations operate numerous facilities, including health centers, schools, community centers and even grocery stores complete with point-of-sale scanners. As far as we could tell, and everyone we asked indicated it was so, Internet access for these facilities, including the IT Training Center and the Jordanian security forces office, is provided via data dongles connected to cellular networks.

Mobile service in the camp is offered by three carriers: Zain, Umniah, and Orange. Many of their towers are located outside the camp and initially were built to serve the small community that existed prior to the camp's development. As reported to us by the refugees, the three carriers' service quality varies, with some being more congested during the day, while others are more congested in the evening, which can be influenced by tariff structures. These concerns were echoed by camp staff, who complained the lack of coverage in the middle of the camp forces them to walk or drive back to base camp simply to consult with colleagues.

4.2 Social and organizational system

The characteristics of the Za'atari network infrastructure are influenced in part by social and organizational systems that enable and support use, including the economic and political power of agencies and the Jordanian government as well as norms of the humanitarian community. In the following, we highlight four characteristics of the social system, namely the camp's economy, UNHCR's policies of equitable treatment, Jordanian government perspectives, and finally a program of SIM distribution instituted by UNHCR.

The camp's economy consists of two elements. The first consists of the system of distribution of food and non-food items (NFIs) by UNHCR and its partners. The second is the refugee-run and financed economy, with both acceptable and black market components. These systems interact to enable refugees to pay for mobile technology and services. Since mobile phone access is not considered a life sustaining need, the costs of these services are not covered by UNHCR.

Refugees earn money to pay for mobile technology and services through several means. First, they may rely on savings they brought with them from Syria or remittances from friends and family in Jordan and beyond. Second, they may operate a business within the camp. The camp hosts approximately 3000 refugee-owned and operated shops, most concentrated on the main shopping street, generating more than 10 million euros per month [14]. Not allowed to legally work in Jordan, they may find illegal employment or a few may be given temporary positions working for the UN and their partners. Finally, refugees may sell their donated food or NFIs on the black market to earn money to pay for mobile services. Black market items can range from simple food stuffs to caravans, the latter becoming available 'for sale' when a family is able to leave the camp. Without these sources of income, revenues for the mobile carriers, investments in the mobile network infrastructure would be unlikely.

In addition to the economy, important organizational factors also influence network infrastructure. One in particular is UNHCR's commitment to providing all services to refugees free of charge. With this commitment, the only option for UNHCR to provide Internet access is to offer it for free. Clearly, free access for 80,000 residents would likely incur enormous backhaul charges for the refugee agency.

This policy has been a particular bone-of-contention in the debates around electricity. Electricity in the residential areas of the camp was first provided to power street lights, which are critical for security, particularly where people must leave their homes to use shared bathroom facilities. Over time, those power sources were diverted to household use through 'illegal' hook-ups. However, the refugee community opposes this characterization, as there are no mechanisms to pay for the service. To solve the problem and meet the ever growing demand for power, UNHCR has considered charging refugee-run camp businesses for power in order to offset the cost of providing it free to homes. However, as studies across the globe show, free electric service leads to inefficient use and a frequently overloaded, and hence unreliable, system.

Whereas UNHCR is concerned with equity amongst the refugees, as is common for most host countries, the Jordanian government is concerned with equity between refugees and its citizens. Consequently, camp development must be planned with an eye toward its position vis-à-vis and impact on the local community. While not nearly as critical as water, Za'atari's power and telecommunications infrastructure development must be carefully planned. Also as is common for host countries, the government of Jordan and local community are likely seeking to ensure Za'atari does not take on an air of permanency and, unfortunately, robust infrastructure can contribute to that perception.

On a more concrete level, a second aspect of UNHCR policy shaping network infrastructure, is its program to provide newly arriving refugees with Zain SIM cards. Many refugees arrive in the camp with mobile handsets and Syrian mobile carrier SIM cards. The prevalence of mobile phones has led UNHCR to distribute SIM cards to refugees during registration as a potential means of staying connected with and providing updated information to refugees. Maintaining a channel for communication between refugees and service providers is a challenge for the service providers. The hope was SMS-based information dissemination processes would solve the problem. However, UNHCR found that without providing voice minutes, refugees tend to use other SIM cards, and hence use of the UNHCR SIMs is fairly limited.

4.3 Cellular carrier service

As shown in Table 1, the cost of pre-paid data bundles vary amongst the three mobile carriers, with Umniah generally offering the cheapest rates and Orange offering the most expensive rates. All of the carriers offer reduced pricing for calls and SMS messages between same-network customers. Jordan's nationwide cellular data connectivity is largely based on 3G HSPA technology as well as 2G EDGE technology. Carriers began to construct 4G LTE-capable infrastructure in 2015; it is generally not available outside of Amman.

		Data Bundle Size		
		200MB*	**500MB†**	**1GB†**
Carrier	**Zain**	2.00 JD	3.50 JD	5.00 JD
	Orange	1.99 JD	4.99 JD	6.99 JD
	Umniah	1.00 JD	3.00 JD	5.00 JD

* Weekly
† Monthly

Table 1: Data bundles available on Jordanian carriers.

The subscriber bases within Jordan for the three carriers as of 2012 are: Zain 3.5M [31], Orange 3.7M [8] and Umniah 2.4M [9]. We discussed wireless carriers with camp residents and were told that Orange is popular in the more urban areas of Amman while Zain is popular for rural customers. Umniah was generally not used by people with whom we spoke. Importantly, Zain is the most popular network in the camp as SIM cards for the network are given to residents by UNHCR as they first arrive and register at the camp.

5. NETWORK CHARACTERIZATION

In this section we examine performance and operation of the cellular infrastructure that serves Za'atari from a user perspective by analyzing cellular control messages as well as signal strength and connectivity logs gathered during our visit.

5.1 Network performance

Given the importance of the cellular network as a sole means of connection for refugees and many organizations throughout the camp, we objectively measure the cellular carrier networks at the community-level by examining GSM air interface messages broadcast by cellular base stations. Where possible, to measure congestion and give an indication of its severity, we compare these measurements with a comparable data set collected in the U.S.

5.1.1 Cellular network congestion

We examine network activity on the camp infrastructure using *immediate assignment* messages, which are sent by base stations in response to mobile device requests for private channels in order to use voice/SMS or data. A cellular base station operating at full capacity such that it is unable to allocate radio resources to serve requests will issue an *immediate assignment reject* message, in accordance to the GSM 04.08 specification, indicating no channel is available for assignment [1]. The link between available channels and immediate assignment reject messages makes this message an excellent indication that a base station is overloaded. Note that the congestion we calculate is attributable to lack of sufficient radio resources at the base station. We do not consider network protocol congestion that may occur due to constrained bandwidth upstream from the base station.

Figure 2 shows the percent of total immediate assignment messages that were rejections over the course of one day[2] for the three carriers. The carriers have significantly different success and rejection rates, where rejections are indicators of congestion caused by an oversubscribed base station. The Zain network experienced the most sustained congestion, occurring throughout the day and frequently reaching rejection percentages above 60%. The Orange network was congested in short, severe bursts. It also appears as though congestion on Orange increases at particular times of the day that correspond with workday schedules (i.e. after 10:00 and before 14:00). Umniah, on the other hand, exhibits almost no evidence of congestion throughout the day. This is expected as the residents we spoke with claimed little to no use of the Umniah network.

Immediate assignment rejection messages include a *backoff wait value* indicating how long a phone must wait until it repeats its request for a resource. Emergency calls are not subject to the wait value restriction. Cellular networks use the backoff wait value to ease congestion on the control channel caused by phones repeatedly requesting unavailable resources in quick succession. The value ranges from 0 - 255 seconds and the advertised value is determined by the level of overload on the base station. We can leverage this value to indicate the *severity* of congestion. Figure 3 shows the observed wait values for the three carriers over the course of the day. It is clear that Zain has the most rejection messages as well as the highest severity of congestion as we see many 128-second waits. Such underprovisioned infrastructure causes a negative impact on user experience, evidenced by two-minute waits to place a voice call, send an SMS, or use data services. We believe that the congestion of Zain

[2]We choose to examine January 6th as it was the day we were able to capture messages without interruption. Additionally, a winter storm on January 7th caused the camp to be closed early. The impending storm may have affected network usage as residents were making preparations.

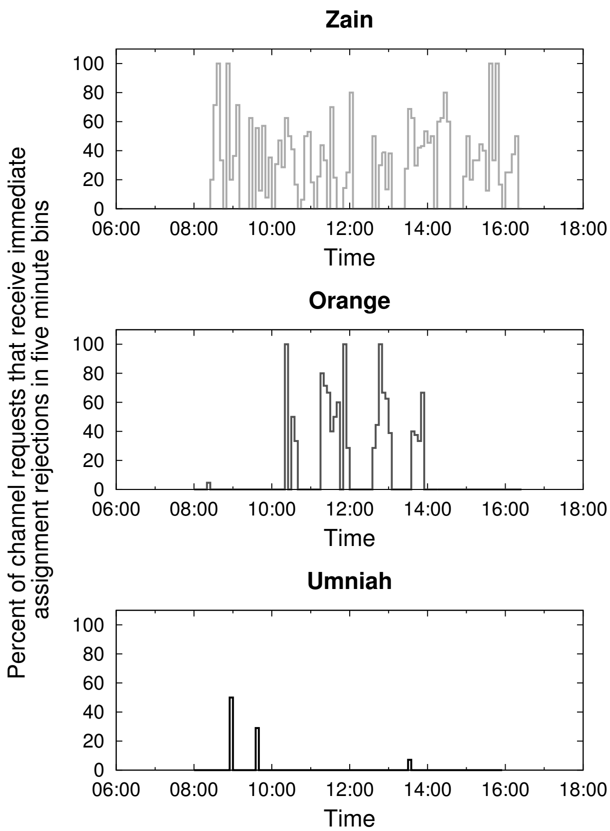

Figure 2: Percent of immediate assignment rejections per five minutes observed in the carrier networks Jan. 6^{th} 2015.

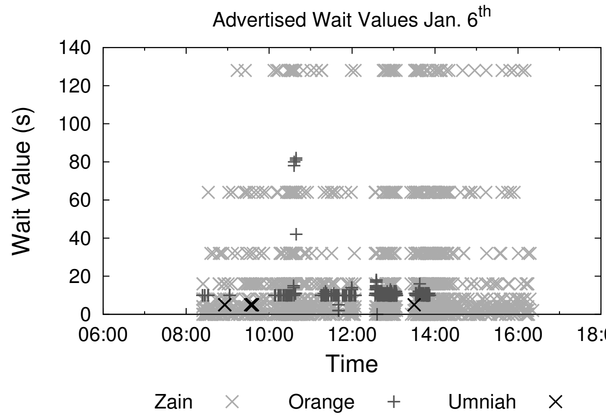

Figure 3: Observed backoff wait values.

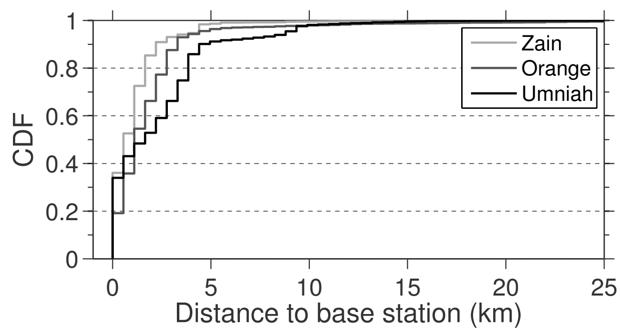

Figure 4: Calculated distances between phones and base stations.

may be in part due to the policy of giving newly arriving residents SIM cards for Zain.

For comparison purposes, we capture control messages on two major cellular carriers in and around Santa Barbara, California (∼90,000 residents) including a mix of urban and suburban base stations. In sum, we analyze 54.16 days worth of capture traffic and find a total of 37,403 immediate assignment messages and only 56 immediate assignment rejections. Additionally, the maximum backoff timer we observe in the U.S. traces is 10 seconds. This comparison suggests the infrastructure serving the camp experiences vastly higher levels of congestion than in the comparison city.

5.1.2 Timing advance

As discussed above, immediate assignment messages are broadcast to all phones connected to a cellular base station. These messages also include *timing advance* information for the phone for which the message is intended. The value indicates, in steps of roughly 3.69μs, how distant a phone is from the base station. Because radio waves travel at the speed of light, we know the timing advance value changes for every 550 meter change in the distance between a phone and the base station. Using the observed values we can therefore estimate distances between all the phones that receive immediate assignment messages and the base station on which our measurement phone is connected. Though this is a rough estimate of distance, we can use it to generally infer the coverage footprint of the camp-serving cellular infrastructure. Cellular carriers configure the coverage area of base stations depending on location and nearby population in order to balance infrastructure costs and ability to serve users. Base stations in densely populated urban areas are typically set to serve small coverage areas, while rural-serving infrastructure has much larger coverage footprints.

Figure 4 displays a cumulative distribution function (CDF) of the calculated distances for each of the carriers. While the majority of distances are within a few kilometers, we see that all three carriers have base stations where users are connected from longer distances. Umniah has the most long-distance users while Zain users experience the lowest distances. Our observations indicate that some of the camp-serving cellular base stations are configured to cover large areas, as in rural configurations. We posit that this may be caused by infrastructure that was installed prior to camp construction as the area was previously rural. The maximum data throughput for a phone is negotiated based on the wireless channel quality between the phone and the base station, which is heavily impacted by distance. Given our observations, camp residents are likely limited to poorer data rates than that which could be attained via physically closer base stations at least some portion of the time. These results could help to partially explain the poor network performance reported in [20].

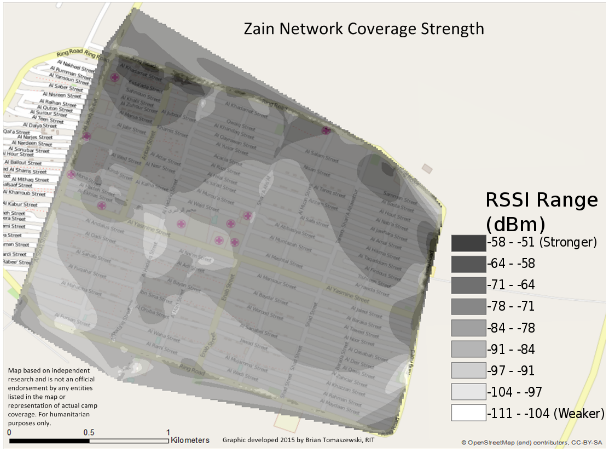

Figure 5: Zain RSSI.

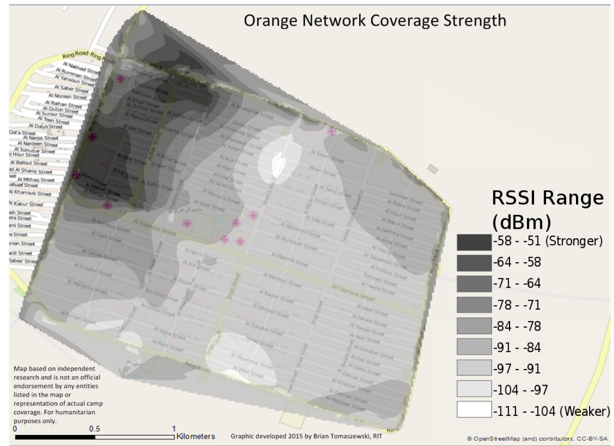

Figure 6: Orange RSSI.

5.2 Geographic analyses

We measure the cellular infrastructure signal strength and data connectivity type with respect to location in order to explore community-level divides of the cellular infrastructure serving Za'atari.

5.2.1 *Received signal strength*

We first investigate the cellular signal strength our measurement phones observed during our time in the camp. Figures 5 and 6 show the collected RSSI values for two of the three carriers, interpolated using natural neighbor interpolation [6]. We do not include an RSSI map for Umniah as our measurement phones failed while we were in the middle of the camp. The highest signal strength values for Zain and Orange are near the entrance gate and base camp, located on the northern edge of camp just east of the entrance. Both carriers generally have lower signal strength coverage in the more residential areas of the camp.

The carriers clearly have different coverage profiles throughout the rest of the camp. Zain, the most popular carrier according to residents, has more locations with high signal strength, particularly focused along the northern edge of the camp. Orange, on the other hand, has very high signal strength near base camp as well as the market area in the northwest area of camp. Interestingly, the vacant food distribution location, depicted as Point D in Figure 1, has extremely high signal strength values. At the time of our visit this location was an abandoned area that had previously been used by the World Food Programme and was now a fenced-off, unused area. Inside of the vacant area was a cellular base station, presumably owned by Orange given our signal strength readings. It is unclear why this location was chosen for an installation, whether it was simply due to convenience, availability of space, or that previous use of the area led to a high density of users, and hence, coverage was needed in this location. The highly variable nature of refugee camps, as evidenced by the changing spatial configurations (food distribution centers convert to unused spaces when people are shifted to western-style supermarkets) makes it difficult to anticipate coverage areas and more important to have flexible network connectivity arrangements. Phones on Orange also collected some very low RSSI measurements in the south central and north central residential parts of the camp. This could be due to shadowing caused by a small hill in the middle of the camp.

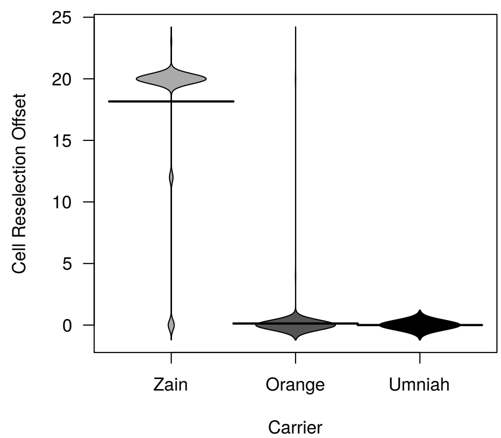

Figure 7: CRO artificially increases the calculated signal strength when the phone determines which cell to use.

5.2.2 *Cell reselection offset*

Cell reselection is the process phones use to choose which base station to utilize. Phones accomplish this by constantly monitoring received signal strength for the base station they are connected to as well as for a list of neighboring base stations provided to the phone by the current base station. In addition to the received signal strength indicator (RSSI), the 3GPP specification allows for carriers to advertise cell reselection offset (CRO) values, which effectively increase the signal strength of a cell in the phone's internal RSSI calculation. The CRO values can range from 0 - 63 with each number representing an increase of 2 dBm, meaning base stations can cause phones to artificially increase the calculated RSSI of a base station up to 126 dBm. Carriers can use this to shape and load balance infrastructure usage in areas by artificially increasing or reducing the 'attractiveness' of base stations for phones.

Figure 7 shows a violin plot with the distribution of offset values that were observed in the camp for each of the carriers, with horizontal lines indicating the mean. Zain, the most popular carrier, makes extensive use of CRO with 87%

(a) Zain. (b) Orange. (c) Umniah.

Figure 8: Data coverage. Color indicates connectivity: 3G HSPA (Green), 2G EDGE (Blue), No connectivity (Black).

RSSI Range	**Signal Level**
>-51 dBm through -65 dBm	Great
-67 dBm through -81 dBm	Good
-83 dBm through -97 dBm	Moderate
-99 dBm through -111 dBm	Poor
<-113 dBm	None

Table 2: Android signal strength RSSI value to level map.

of messages advertising a CRO of 20, resulting in an artificial increase of 40 dBm. The effect of such an increase is illustrated in Table 2, which displays the mapping Android uses to convert RSSI values to 'levels' that define how many signal strength bars are displayed on a phone. For example, a 40 dBm increase would cause a phone to view a 'poor' signal of -100 dBm as a 'great' value of -60 dBm. Thus, while the phone may indicate to the user strong connectivity to the base station, in reality it may have a very weak connection. Traces from the other two carriers included very few non-zero CRO values.

We inspect the cellular IDs of the Zain base stations that advertise non-zero CRO values. We find that the data connectivity on all of those base stations was limited to either 2G EDGE or no data connectivity (voice/SMS functions without data). We did not observe any 3G Zain base stations in the camp utilizing CRO. While the precise reasons behind such a configuration are unknown and could be attributable to Zain purposely engineering capacity planning into the deployed infrastructure, the overall effect of the configuration is to steer mobile devices on the Zain network toward 2G base stations serving the camp. This can be detrimental for some users as phones 'prefer' the artificially-enhanced base stations even when they may be better served by a base station with a higher real-world RSSI value. Such a configuration could be desirable in areas where a carrier aims to reduce the service footprint of 3G base stations not using CRO, as phones will only connect to the CRO-disabled 3G base station if they detect very high RSSI values (i.e. they are physically near the base station). This can advantage users in close physical proximity to a base station, such as those allowed inside base camp.

Our measurements indicate that base stations using CRO often failed to provide any data connectivity. This is a sign of congestion, which is a logical outcome of a base station appearing to client phones as having very high signal strength, thus increasing the number of phones that attempt to use it. Essentially, the base stations advertising high CRO values worsen user connectivity in two ways: they attract devices away from nearby 3G base stations onto 2G base stations, and this attraction consequently causes the farther-away 2G base stations using CRO to be more heavily used and thus more highly congested.

5.2.3 *Data connectivity*

Beyond signal strength, we collect the data connection *types* during our measurement for the carriers. All three carriers have 3G HSPA and 2G EDGE connectivity in some portions of the camp. We configure our measurement phones to prefer 3G connectivity and record the actual connectivity as we travel around the camp. Figure 8 shows the attained data connectivity types for each of the carriers. Similar to the signal strength maps, we observe that the best data connectivity speeds are attainable in the northern areas of the camp and near base camp for the carriers. Zain's 3G connectivity (Figure 8a) is mostly focused around the northern road along with a few small areas around the perimeter of camp. Both Zain and Orange (Figure 8b) have areas with no data connectivity in the north central area of camp; Zain also lacks data in the southwest area of camp. Orange has the smallest area of 3G coverage, with the majority of the camp covered by 2G EDGE connectivity. Umniah (Figure 8c), the least popular carrier according to residents surveyed, has the highest number of points indicating 3G coverage.

One reason for the lack of widespread 3G connectivity is low antenna height. While in base camp, we observed a base station with antennas placed roughly 5 meters above the ground, a height that results in a small service footprint. In this case the base station's location within base camp and the height is likely chosen to purposely limit the service area. Our general observations of data connectivity are that 3G coverage is focused around administrative and NGO locations, while residential areas are largely covered by 2G EDGE connectivity.

Generally, the southern areas of the camp have slower data speeds compared to the northern areas. This is important as UNHCR has expressed the intent to increase spatial distribution of both services and residents in the southern and eastern areas of camp; these areas are quite sparsely populated while northern and western are dense. Some residents have resisted these efforts of relocation. While certainly not the sole reason, data connectivity speeds could impact the desirability and livability of locations in the camp.

6. ANALYSIS AND RECOMMENDATIONS

In the following we combine the technical with social and organizational analyses to dimensionalize and explain the observed camp-based community-level digital divides. In so doing, we provide further evidence of the significance of the social informatics frame, highlighting specific aspects of their mutual shaping and providing a sound basis for recommendations for practice. This analysis also highlights the subtle ways network design and operation contribute to divides, as well as the ways in which they are reflective of differences in societal economic and political power divides. Finally, our analysis highlights how social systems, namely the policies and practices of the humanitarian relief sector, constrain optimal solutions.

Our technical analysis identified three general physical access divides across carriers, space, and consumer groups, taking the forms of: congestion, uneven spatial distribution in services, and inter-network access. In the following we examine these dimensions, identify their social / organizational / humanitarian influences, and offer recommendations for residents and camp management.

6.1 Congestion

Traditional notions of physical access divides are premised on a dichotomous state of infrastructure availability and supplier bias, relying on their reports of (lack of) service coverage. The user-oriented view here provides more nuanced perspectives on access divides, identifying service quality differences between carriers. Whereas in places where users are more likely to switch back and forth between carriers via unlocked handsets, an inter-carrier congestion divide can be overcome by information like that provided here. In countries (e.g. U.S.) where users are frequently locked into contracts, these divides may have longer term effects.

These congestion divides are indicated through comparisons of carriers' immediate assignment, timing advance and CRO measures. In general, we find high levels of congestion but also significant differences between carriers. Three social and organizational factors affecting congestion are: (1) the camp's booming economy, which is somewhat unique and enables refugees to pay for service; (2) the failure of camp management to provide alternate fixed network infrastructure due to a variety of organizational factors (equity, financial, resisting permanancy); and (3) UNHCR's SIM card distribution program with a single carrier (Zain). Critical network design elements affecting congestion include the number of base stations serving the area and their configuration.

To overcome the carrier-based congestion divide, residents can apply our findings to make more well-informed carrier selection decisions by using the least-used carrier, Umniah. We witnessed almost zero immediate assignment rejection messages on the Umniah network while Zain and Orange both had numerous rejections.

Camp management can help ease congestion by designing SIM handout programs such that beneficiaries are spread more evenly across carriers. Further, camp management might also consider providing an alternate network beyond base camp to provide options for the service providers. By taking local camp-based service provider traffic off the cellular network, congestion might be reduced.

6.2 Uneven spatial distribution in services

Our analyses also identify a spatial distribution divide, complementing research on urban/rural and 2G/3G divides (e.g. [19]). However, our higher level of granularity identifies precisely where 2G and 3G service is available and how local economic and political inequalities are reflected in those spacial patterns. These analyses are strengthened by our ability to compare patterns among carriers, finding similarities and differences supporting or refuting various hypotheses.

Spatial distribution is indicated by several measures. Received signal strength is measured and extrapolated across an area. This is complemented by measures of different types of data access (2G vs. 3G) along the roads, and finally these were complemented by CRO measures which may have been used to bias traffic away from 3G base stations. As shown in Figure 8, we observed marked differences in connectivity based on location in the camp. 3G connectivity varies between carriers but can generally be obtained near UNHCR base camp and in the northern areas of camp, while the southern sections of the camp are limited to 2G EDGE.

The uneven spatial distribution of signal coverage and data availability has likely been influenced by several social and organizational factors. The first is simply changes in land use as the camp has grown. The need to adjust land use as circumstances change is one of the ongoing challenges of humanitarian response, particularly as it relates to infrastructure. The less densely populated areas and most recently settled have both lower signal strength and poor data coverage.

A second social factor potentially affecting spatial distribution is the political and economic power of the agencies located in base camp, where both signal coverage is strongest and 3G data availability is highest. It is unlikely those organizations are aware of this benefit. More likely is network operators are seeking to please their most important client.

To ameliorate this spatial divide, residents and service providers may want to purchase SIM cards for multiple carriers, taking advantage of Umniah's 3G availability and reasonable coverage from time to time.

As for camp management, we have two recommendations. During our visit, they discussed the desire to spatially redistribute services as well as residents to sparsely populated areas of the camp, particularly the southern and eastern areas. We have found that the data connectivity in those areas is relatively lacking. While connectivity is not likely the sole reason for resistance to living in any particular area, it can be a factor. As such, camp management should engage in discussions with cellular carriers to appropriately plan infrastructure enhancement in locations where residents are to be relocated.

Our second recommendation is to repurpose the former WFP food distribution center to a purpose that takes advantage of its network coverage. At the time of our visit, we detected excellent connectivity and favorable RSSI values. Given the proximity to the market area of the camp as well as the connectivity, we encourage careful consideration of its future use.

6.3 Inter-network access

The third divide is slightly different from the first two in that it considers potential rather than actual access. The inter-network physical access divide exists between camp management and the refugees, where refugees are not provided access to UNHCR's fixed network. On the one hand, it may seem unreasonable to label lack of access to a privately arranged and financed link as a divide. However two interrelated findings support our claim. First, there exists significant economic and political power differentials between refugees and camp management, including the UN and Jordanian government, that hinder refugees' provisioning their own infrastructure. Second, to date, UNHCR's microwave link is the only fixed network in the camp we are aware of. Media reports suggest private firm's efforts to provide additional fixed infrastructure for others in the camp have been blocked by the Jordanian government. If the temporary nature of the camp is playing a role in limiting fixed infrastructure deployment, then we consider this a legitimate divide. Further, as compared to many other locations worldwide where combinations of fixed and WiFi networks allows users to save money, the result is that traffic is offloaded from cellular networks, easing congestion. The existence of this inter-network access divide is influenced by a variety of social and organizational, including economic and political, disparities, as well as norms in the humanitarian sector that accept camps as temporary solutions, which in turn hinders infrastructure development.

In the short term, residents and service providers in the camp might continue to push for greater access to fixed infrastructure, challenging norms. A second alternative is to deploy a camp-wide network for internal camp traffic, which will not provide the benefits of fixed network access but at least provides an alternative and potential solution for minimizing traffic on the commercial network.

7. CONCLUSION

Our work examines community-level access divides from a technological and organizational perspective and illuminates many avenues for future research. We observed congestion that may, in part, be attributable to UNHCR funneling camp residents onto a single mobile network (Zain). As such, we suggest improved service could be attained by spreading SIM handouts across carriers. A challenge arising from this surrounds maintenance of social networks within a single carrier, as users would undoubtedly desire the same carrier as friends and family due to reduced-cost in-network voice/SMS.

Given the highly dynamic environment of refugee camps and the lack of permanence, rapidly-deployable cellular infrastructures present an interesting potential direction. Recent work has deployed local cellular networks [13, 12, 32] in remote areas without existing service. Successful deployments by nonprofit organizations show that it is technologically and economically feasible for agencies like UNHCR to deploy and operate their own 'pop-up' cellular networks, which can quickly expand and shrink in concert with the demands of a refugee camp. The challenge posed by Za'atari is the presence of existing cellular service, as any local cellular network would be required to coexist with incumbent carriers. Such a scenario was explored in [24] using an application designed for rooted Android smartphones to programmatically duty cycle between commercial and local cellular networks without requiring user intervention.

Our investigation characterizes community-level divides so that they may be narrowed. We observe inter-carrier divides in the form of congestion, a spatial distribution divide throughout the camp manifested in different levels of connectivity, and an inter-network divide between camp residents and users of fixed data infrastructure. Our hope is that by using information gleaned from our analysis, refugees and camp administrators can more effectively leverage the limited available technology.

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