Immaterial Materials: Designing with Radio

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ABSTRACT
Designing with digital materials is sometimes challenging due to material properties that are for all practical purposes invisible. Here we present our work on exploring one such material, radio, and how we have worked with making radio a more tangible and accessible design material for multidisciplinary design teams to work with. Starting from an account of a previous project of ours, the LEGA project, we describe a design situation involving radio that exemplifies some of the challenges that working with radio can involve. We thereafter describe how we have used the *Inspirational Bits* approach to further investigate the peculiarities of radio as an immaterial design material and what possibilities it holds for interactive systems design.

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Design, Design Material, Radio communication

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Experimentation.

INTRODUCTION

Design in the digital realm is faced with particular challenges, as properties of involved technologies are often hard to observe and thus experiment with. In some cases such properties are for all practical purposes invisible.

An example of such a technology is radio communication, which exhibits behavior that does not match our intuitive, albeit somewhat naive, understanding of how it works. For instance, most of us have no doubt wondered at the mystery of how radio devices can fail to communicate despite being separated by a very short distance, or how one device can communicate with another but not the other way around. Often such failures are blamed on the technology itself (e.g. a bad transceiver), when in fact they may be a result of the way in which radio waves naturally propagate. However, as we have no way of directly sensing radio waves we are left in the dark about what is actually going on. This property of radio waves makes it challenging to design applications that rely on wireless communication.

Misconceptions and lack of knowledge about wireless communication is widespread. Even in research communities devoted to the topic overly simplistic assumptions are made and wrong simulation models are used [7]. For instance, protocols for wireless networks have usually been created for static networks. With devices increasingly becoming mobile such protocols fall short as mobility poses very different demands on the network and turns many assumptions on their head [3].

As various forms of radio communication (e.g. Bluetooth, ZigBee, Wi-Fi networks etc.) increasingly come into play when designing digital artifacts, in particular in mobile device and service design, finding ways for designers and developers to understand and work with this invisible material becomes important. The current evolution of an Internet of Things [17] consisting of billions of connected, and interconnected, objects/devices in our everyday life will further necessitate such a development.

In addition creating connections between devices is only one possible use of radio. Familiar examples of other kinds of use include microwave ovens for heating food, radar for keeping track of air and sea traffic, AM and FM radio for broadcasting news and entertainment, and so forth. Hence, instead of a technology limited to point-to-point connections the view we take is that of radio as a digital design material that can be shaped and molded to fit a wide variety of purposes, much like more traditional materials such as clay or paint.

Here we use a previous project of ours, the LEGA project [8], to outline some specific issues we have had when working with radio in the design of interactive systems. The paper then continues to present how we have learnt from the LEGA project and constructed what we in a previous paper of ours refer to as *Inspirational Bits* [15] as a tool for working with radio in design situations. Inspirational Bits are quick and dirty designs developed with the single aim of exposing the properties of digital materials, here radio, in a way that all members of an interdisciplinary design team can understand and use. Bits are not meant to be early iterations of a prototype but rather, as the name indicates, are meant to be "one bit" designs that highlight particular

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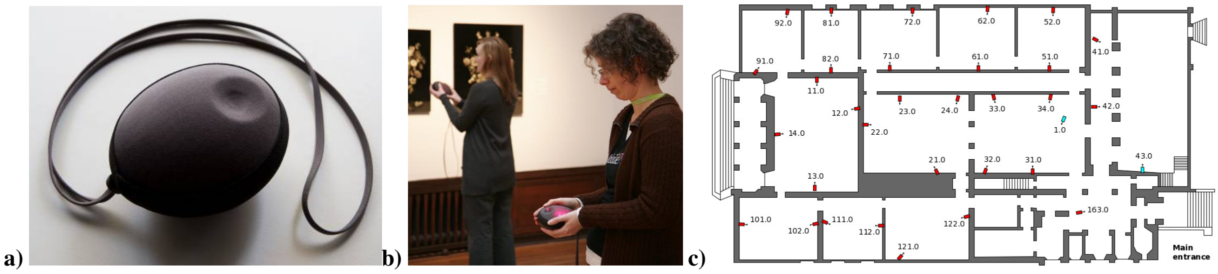


Figure 1. a) A close up of the LEGA b) The LEGA in an art exhibition c) Map of the exhibition with the infrastructure nodes

properties of a design material and point out possibilities for design. Here we present six of the Inspirational Bits we have developed to make radio as a design material less immaterial, both for ourselves and others, in future projects.

A CASE STUDY OF RADIO DESIGN – THE LEGA

The LEGA is a hand held device that allows visitors to an art hall to share their experiences via physical traces that are created through gesture and touch. The device was created for the Vårsalongen event at Liljevalchs art hall in Stockholm, Sweden, which exhibits professional and amateur art selected by a jury from anonymously submitted pieces. Each year around 250 pieces are exhibited for a period of two months. The event is visited by approximately 40.000 visitors each year and has a long-standing tradition of stirring up emotion and engagement from both visitors and media.

The LEGA device has an ovoid form that fits into the palm of your hand and has a soft surface that encourages tactile and gestural interaction, see Figure 1a. By touching and moving their device in various ways users create expressions, or traces, of their experience that are left at their approximate location. There they can be discovered and experienced as vibration and light patterns by others in the group (see Figure 1b) passing by that location in the exhibition space.

The LEGA makes use of radio in several ways. First and foremost radio is the basis for the positioning system that was used to determine the location of LEGAs and traces. The system relies on an infrastructure of radio devices that at regular intervals transmit their id number using low transmission power. From the radio signal strength of received beacons and number of beacons received in a time slot, LEGAs can acquire an approximate location. In total 31 infrastructure devices, corresponding to an equal amount of locations, were placed around the art hall (Figure 1c). Secondly radio is used to transmit trace data between the LEGAs and the infrastructure where it is stored. When a trace is left it is transmitted to the infrastructure node that corresponds to the location of the LEGA leaving the trace. When a LEGA acquires a new location any traces that are stored on the infrastructure node are transmitted back to the LEGA.

In our work with the LEGA system we encountered several difficulties while working with radio. Firstly, due to the immateriality of radio communication it was occasionally very hard for the design team to understand what was going on. For instance, traces would seemingly be lost, or found at locations where no traces could have been left which made it very hard to verify that the system was functioning properly. Finding an explanation to these behaviors required lengthy investigations and extensive experimentation. For instance, we found that some infrastructure devices were placed in spots where their transmissions could be heard through walls accounting for the mysteriously appearing traces, or radio traffic congestion preventing traces from being sent or received by LEGAs, accounting for the lost traces. The latter was a consequence of the way the protocol handled transmitting to all nodes in range in a power saving network. In the end we were able to overcome most of the peculiar behavior by moving around the infrastructure devices to more suitable locations, adjusting their transmission power, and rethinking a basic communication principle, from push to pull, to avoid congestion and overhearing [9]. However, even finding the source of the problems required a substantial effort, which could have been avoided, if we would have had access to better tools for exploring such issues at an earlier stage in the design process.

During our work we also encountered behaviors caused by the nature of radio waves that worked to our benefit. A prime example of such behavior was due to the absorption of radio waves by human bodies. One of the worries we initially had was that transmissions from the infrastructure beacons would not reach far enough. Hence, we started out by placing them on ledges high up (about 5 meters) in the art hall to avoid obstacles. This turned for the beacons to be heard in locations up to three rooms away. When we instead moved them down about half a meter the positioning system suddenly worked substantially better. While we were initially confounded by this we soon found out that by placing the beacons at a height where the crowd visiting the exhibition would actually absorb radio waves, we prevented transmissions from leaking to adjoining rooms and thus made the locations more exact. From a strictly technical point of view this behavior could have been foreseen, but from a design point of view it was not until we actually encountered it that we could understand it, and see the usefulness of it. Here the immateriality of radio, and lack of tools for exploring it, prevented us from recognizing an opportunity for design at an earlier stage of the process.

The LEGA device was realized as a multidisciplinary design effort involving a wide range of competences such as industrial design, hardware and software engineering, as well as a HCI design. This combination of competences is necessary to build a system such as the LEGA. However, it also posed us with unique challenges in making sure that the whole design team understood the challenges of working with radio during the LEGA design process. The issues we encountered were problematic to get a grip on even for those in the design team that were best equipped to do so, the engineers. For others, such as industrial and interaction designers, it was near impossible. As a result it was hard for them to take such things into consideration in their design work.

It is rare, although not unheard of [2] to find people skilled in both the kind of creative design and engineering that are required in order to innovate, design and develop systems such as the LEGA. In addition, systems such as the LEGA are very hard, if not impossible, to fully design without trying them out and experience them in practice.

What became apparent in the LEGA design process was that in order to work out and realize systems of this level of complexity, designers and engineers need to find better ways of communicating and working together, that takes into consideration the varying areas of expertise that team members have. Designers on the one hand need to develop ways to express their creative thinking in an understandable form to non-designers [10] and engineers on the other hand need to find ways to illustrate and explain properties and behaviors of digital materials such as radio for non-engineers in a way that turns them into resources for design. Sculptors sometimes claim that they are only bringing out what is already present in the material they are working with. In the same way digital design materials need to come alive for designers so that they can bring out the designs and interactions that lie dormant in the material.

As the engineers of the multidisciplinary design team working out the LEGA design we encountered these challenges first hand. We found the behavior of radio especially problematic to explain and also sometimes understand ourselves. Even though we all could see the infrastructure devices and discuss them by acting out various scenarios, parts of the design team still found it hard to understand how the radio communication worked, and why it was so hard to use the radio signal strength to calculate distance and position, or even how this could be done in the first place. Therefore, when later starting our design exploration – or uncovering of – radio using the Inspirational Bits approach we first set out to make the issue of using radio and RSS as a means to indoor positioning more understandable. But first, some basic facts about radio.

BASIC FACTS ABOUT RADIO

Radio waves are electromagnetic waves that can be used for information transfer by modulating the waves, i.e. changing some basic properties of the waves such as the amplitude, frequency or phase, to encode information. Radio waves are transmitted by applying an oscillating electrical current to an antenna. Receiving antennas transform it back into an oscillating electrical current that can be decoded to reveal the sent information.

In this paper, radio communication in the microwave spectrum (centered around 2.4 GHz) is the main focus. This frequency band is used by communication technologies such as Bluetooth and ZigBee, as well as many consumer devices using proprietary communication protocol stacks. The microwave spectrum is popular as it is open for use in almost the entire world, in contrast to other spectrums that require special permits to use. However, to some extent, the results and insights reported in this paper also holds true for other spectrums and technologies communicating via radio.

Radio Signal Strength, Absorption, Reflection and Asymmetric links

One fundamental metric of radio waves that we already have mentioned is the received signal strength (RSS). This is a metric in decibel (dBm) for how strong a signal is at the receiver. RSS decreases with distance and is therefore sometimes used for indoor positioning as the Global Positioning System (GPS) signals cannot reach there. However, as the RSS also decreases with environmental factors, such as the existence of attenuating materials, such positioning is not always reliable. For radio waves in the microwave spectrum, the frequency corresponds to the resonance frequency of water, thus anything containing water will be particularly good at absorbing radio waves (which incidentally is the basis for how an ordinary microwave oven functions). An average person contains 45-60 % water and thereby functions as an excellent attenuator, but also other materials are attenuators. Metals are generally reflectors and instead reflect radio waves, which causes reflections that at the receiver can cause a decoding to fail as multiple waves arrive with slight variations in phase and amplitude, causing destructive interference. The effects of this superposition of radio waves, is commonly called *multipath phenomena*. Sometimes multipath can however improve communication as when adding up all the different paths being in the same phase, the signal becomes stronger.

A counter-intuitive observation due to such phenomena is *asymmetric links*, where communication does not work both

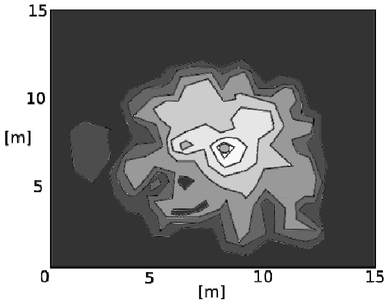


Figure 2. Heatmap showing the probability of receiving a packet from a device positioned in the center. Note that it does not look like a uniform disc. After results acquired experimentally by Ganesan et al[4].

ways. Device A can hear device B, but not the other way around. This is repeatedly seen in real world deployments and experiments [4]. Radio links also exhibit burst properties. The probability of successfully receiving a transmission is dependant on how many transmissions were successful or unsuccessful just before it [14]. The reason for this is in part unknown, but a suggested cause is the almost ubiquitous 802.11b wireless networks, where signals are on the order of 1000 times stronger than the typical ZigBee device.

Due to multipath phenomena and reflecting/attenuating materials the probability of receiving a packet – the combination of a message and metadata – will not just depend on distance to the transmitter. Figure 2 shows a map of the probability of receiving a packet from an experiment conducted in an open parking lot. It clearly shows the irregular and volatile nature of wireless communication. In addition the reception landscape shown in Figure 2 is highly dynamic, shifting over time as conditions change.

Because of this, packet loss is something that has to be taken into account. One way to do this is to wait for an answer that it was received. If this acknowledgement (ACK) is not received within a set period of time, a retransmission will occur. After a number of unsuccessful retransmissions the application will be notified of the failure and can for example try sending to another device or show an error message. This is called a *reliable transmission*. The opposite is a *best effort transmission* where ACKs are not used and the sender will not know if the receiver has received a package sent.

Network Communication and Topologies

A set of devices communicating via radio forms a wireless network. In such networks there is a logical structure for how the devices coordinate communication with each other, called a network topology. The choice of topology, e.g. ring, star, mesh or bus, is done either implicitly as it sometimes comes with the choice of technology such as Bluetooth or ZigBee, or explicitly if another abstraction layer is put on top of the technology. Topologies differ for example in latency, physical layout, message passing order and how and how well they cope with transmission failures. For instance, in the ring topology, each device is connected to one device in the forward direction and one in the backward direction. A message is sent in one direction (e.g. clock wise), and changes direction if a failure is detected. The star topology has a master device in the center and slaves surrounding it. Slaves cannot send directly to another slave, but the message must always pass the master. This makes it more robust to failures as long as it is not the master that fails.

Lifetime is another crucial factor for devices communicating via radio as it consumes a lot of energy. A common way to preserve energy is to shut down the radio for as much as possible. Some applications only have their radio on for about 1 % of the time. In order to transmit to a neighbor that sleeps, one way is to repeatedly transmit the same information or a wake up packet until the receiver hears it when it periodically wakes up to listen. Because of this, sending to all neighbors in range can be more costly than sending to one single neighbor [10], and it also adds to congestion in the wireless medium, blocking others from transmitting as well as causing interference.

Many of the above properties of radio communication may be common knowledge to researchers, designers and engineers working in the field of ubiquitous computing. But it is when that is not the case, when radio communication is assumed by some to be just a wireless equivalent of wired communication that we in interactive systems design teams sometimes start to get problems. In the following, and with an eye on design, we take a more detailed look at these underlying features of radio and how we can come to a shared understanding of these properties, when working out interactive systems designs in multidisciplinary design teams.

RADIO AS A DESIGN MATERIAL

Through sketches, mock-ups and early prototyping, designers engage in a "*conversation with their materials"* [12]. In the formation of new ideas materials start to "*talk back"*, revealing design opportunities and challenges. Digital materials— including both hardware and software— are however sometimes complicated for designers to work with [9]. An important aspect of digital materials, differentiating them from other materials, is that they typically have a temporal aspect to them. Over time properties reveal themselves and change in interaction, providing new and sometimes unforeseen use experiences [5]. Thus, it is not enough to experience digital materials at any given moment to grasp their properties and design potentials; instead such dynamic qualities only reveal themselves when put to use. More often than not they have to be assembled as part of running systems for properties to take on form and substance, and especially so for materials as immaterial as radio.

There are many examples of projects where radio communication has been used as a design material in one way or the other. Chandrasekaran and colleagues [1] used RSS from GSM cell towers to approximate vehicular speed for road traffic congestion monitoring. Kim and colleagues used the identity of cell towers and wireless access points, snooped from radio beacons, for discovering locations that users visited [6]. Rose and Welsh [11] placed wireless sniffers across a city landscape to snoop on beacons and traffic in order to detect and measure usage, traffic, mobility and more. The Yourban project[1] at the Institute of Design at Oslo School of Architecture and Design has worked on several prototypes specifically addressing the immateriality of radio. For instance, "Light painting Wi-Fi" where they visualize Wi-Fi radio signals in the streets of a city or "Ghost in the field" where a radiation pattern from a RFID antenna is visualized. These last two examples have been made by designers using radio as a design material and source of inspiration.

But, as previously said, it is not always that one person alone is skilled in both creative design and explorative engineering, nor are collaborations between designers and engineers always easy and productive. Many times the immaterial aspects of a design material such as radio are hard to discuss and come to grips with and this is when we need methods and tools for how to communicate between competences in order to come up with cool innovative ideas for design and also set them to life. In order to help those who engage in design with digital technologies, we thus need to consider how we can systematically and critically expose dynamic qualities of digital materials in ways that make sense to designers, HCI-experts and other non-expert members of multidisciplinary design teams.

With this in mind, and as a first step in this direction, we in a previous paper of ours introduced the *Inspirational Bits* approach [15] as a way for engineers and developers to "*unfold the design space"* by experimenting with digital materials.

RADIO USING THE INSPIRATIONAL BITS APPROACH

In total we built six Inspirational Bits that explored various aspects of radio ranging from network topologies to RSS. For our work we have used the Tmote Sky[2] sensor node, which is a popular platform in the research community. It has an 8 MHz microcontroller, a 2.4 GHz short-range radio transceiver, a 1 MB flash memory and environmental sensors (light, humidity, temperature). In addition, we have used a very similar platform, the Sentilla JCreate[3] sensor node that, instead of environmental sensors, has a three-axis accelerometer, a set of LEDs and comes in a casing comfortable to hold in the hand. Both platforms/sensor nodes are shown in Figure 3.

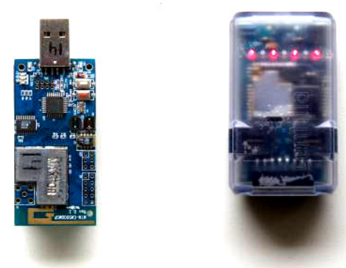


Figure 3. The wireless sensor nodes used for the bits described in this paper: to the left the Tmote Sky sensor node, and to the right the Sentilla JCreate sensor node.

Bits on Radio, RSS and Positioning

Not only in the LEGA project but in several of our previous designs (e.g. [16]) we have encountered problems with wireless sensor networks, radio communication and using RSS as a means to indoor positioning. Therefore, in starting our design exploration of radio, we first set out to try to make immaterial properties of the radio signals more 'material' and thereby easier to grasp. We built three bits for this purpose, one turning the RSS into sound, a second trying to explain the difficulties of using signal strength as a means to indoor positioning, and a third that shows how the absorbing properties of the human body, can be turned into a game feature rather than being a limitation.

Our first bit, RadioSound, turns the RSS into sound and thereby 'materializes' how the signal strength is affected by the environment and the human body. RadioSound consists of two sensor nodes: one is a JCreate node that is equipped with a small speaker emitting a single tone, while the other is a constantly transmitting Tmote Sky sensor node. The pitch of the emitted tone increases with the signal strength between the two nodes. Using these sensor nodes one can walk around in the environment noting how the tone changes as the signal is affected by other materials such as walls, furniture and especially metal and human bodies.

In order to explain how the signal strength measurement is very unstable due to changes in the environment or fast movement of the nodes, we decided to build a second bit this time using a graphical representation of the RSS. In this second bit, that we later turned into our GoldRush game (explained below), the size of a graphical circle visualizes the signal strength measurement, where fluctuations or instability in the signal strength can be observed as the circle disappears completely when there is no signal at all and comes back again when the signal stabilizes. Using this bit one will see how the circle disappears when a node is moving too fast or the surrounding environment is changing or moving (people and furniture), and how the signal then

[1] www.yourban.no

[2] http://www.moteiv.com

[3] http://www.sentilla.com/

a) b)

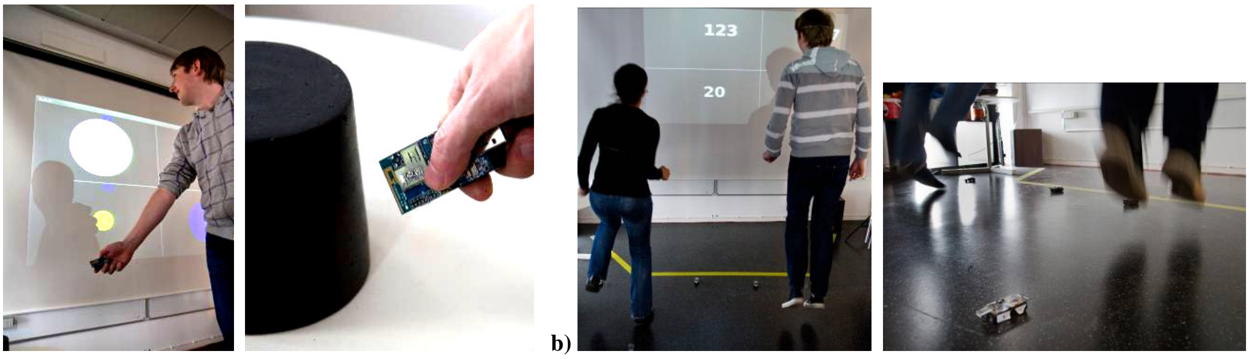


Figure 4. a) Gold Rush bit, interface and Tmote sky node used for seeking b) The Gymkhana bit, two players playing the game

again stabilizes when holding it still for a while. Also the circle flickers more if the transmitter node and the moving node are far apart, as they then are more affected by the environment.

GoldRush explains the difficulties of using the RSS as a means to indoor positioning by letting the inconsistency in this usage of radio be the game feature itself. In Gold Rush, one hidden Tmote Sky sensor node is set to constantly transmit. Four users are then set to look for the transmitter by walking around with a Tmote Sky sensor node that listens for the signal. The RSS of each player is shown as above using a circular shape displayed on the wall, see Figure 4a. By playing the game four users at a time they need to understand the concept of how their body and movement make the RSS fluctuate. In order to get a more stable RSS it is better if no one is moving in the room. Here users can choose to either cooperate, ask each other to stay still for a second and get a stable RSS reading, or move about thereby diminishing the chances for other players to get a stable reading.

Playing with this bit we also got the idea of using the body itself as the moving part, and let a set of positioned sensor nodes 'measure' the amount of movement between them, see Figure 4b. , by measuring how the signal is absorbed and disturbed by moving bodies. This turned into the Gymkhana game, where the idea is to first move as fast as possible to disturb the radio signal and thereby gain points, and then not lose those points by acting out a set of full body movements without disturbing the radio signal. Up to four Tmote Sky sensor nodes are placed on the floor or on some stable furniture around the body of the player, and they transmit continuously to each other, which makes the body of the participant become an obstacle for the signal. The more users move their bodies, the more the signal is disturbed. Gymkhana is intended to make the user understand how her body affects the radio signal but also how limitations of this material themselves can be used as possibilities for design.

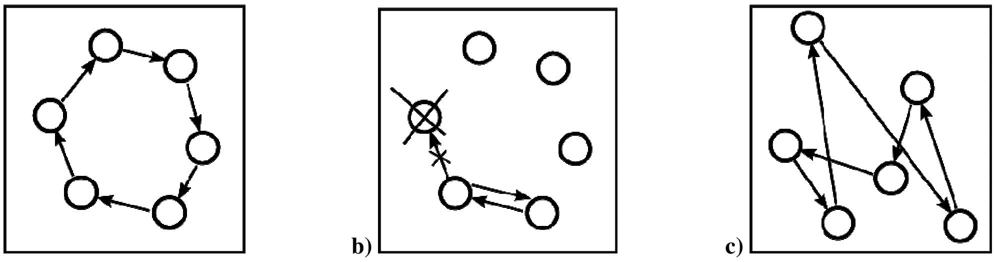
In summary the most important aspects of radio that were explored by these Inspirational Bits were:

- RadioSound – turns the RSS into sound and thereby 'materializes' how the signal strength is affected by the environment and the human body
- GoldRush – explains the difficulties of using the radio signal strength as a means to indoor positioning by letting the inconsistency in this usage of radio be the game feature itself
- Gymkhana – is meant to make the user further understand how her body affects the radio signal, but also how previously thought of limitations of this material can be used in themselves as possibilities for design.

Bits on Radio, Topologies and Communication

We also wanted to build a set of bits explaining how even something as the topology set up can be used as a in design. Network topologies are typically hidden from the user under layers of abstractions, though we felt there could be value in showing the topology explicitly; show how it works and how it in fact already does affect the user experience. For example, the slow speed at which Bluetooth connects is in part due to the network reorganizing as devices listen for neighbors and sets up a synchronous protocol. So to further explain the concept of topologies and to explain how they work and point in directions in which they can be used we built three inspirational bits: the ComNet bit, the RobustNet bit and the GeoNet bit.

ComNet (Figure 5a) shows how the packet passing order differs between network topologies and how that can affect the user experience. One JCreate sensor node per participant is used, first set up as a star and later a ring topology. One of the nodes injects a packet that is then automatically passed on in the topology. Every node keeps the packet for a while and then passes it on to the next node following the message path set by the topology. LEDs lit up indicate that the node has the packet, and only one node at a time can have it. At least three participants are needed, who



a) b) c)

Figure 5. Illustrations of the topology bits in a ring topology setting a) ComNet, showing the message passing order b) RobustNet, showing how it handles a failed transmission c) GeoNet,showing that physical position can differ from logical

are given one sensor node each. To get the participants to further engage with the material and thereby better understand it we turned this into a game where the goal for the team was to, in the shortest possible time, physically move the message by moving the nodes from the starting point to a target area, approximately 50 meters away, and back again. The person having the packet is not allowed to move but has to wait for it to be transmitted to one of the other nodes, which then hopefully is closer to the target area. Which node that gets the packet depends on the packet passing order of the topology and the connectivity between nodes. To let the participants get the time to understand how the passing order works, the radio in the nodes was set to a maximum transmission range of approximately 10 meters. Using this bit in a star topology setting, one participant has to run more than the others as that participant has the master node and as mentioned, in the star topology, all packets always pass through the master. In the ring topology setting, the team has to figure out in which direction the packet is passed on so that they can move the packet forward towards the target area.

Our second bit on radio, topologies and communication, RobustNet (Figure 5b), shows how topologies differ in terms of robustness and what happens when something goes wrong. Here 'wrong' means that a communication fails due to e.g. a node running out of battery, is broken or moves out of transmission range. The same setup as in ComNet is used, but this time the participants are encouraged to keep extra long distances from each other to make the nodes lose connectivity as they are out of transmission range, to turn off their nodes, or to hide them. This was done to provoke more packet losses and (simulated) node failures while observing what happen with the network communication.

Finally, our GeoNet bit (Figure 5c) shows the difference between physical and logical positions in a network. This bit was not made as a game, but rather as a quick explanatory bit as the message it conveys is similar to the ComNet bit, but still different enough to justify a new bit. A topology might imply from its name that the devices should be placed in e.g. a ring, but that does not have to correspond to the actual placement of the nodes in the physical world, but merely how the nodes are addressed in a logical sense within the network. Yet again, the same setup as above is used. This bit was used right after the RobustNet bit, before participants gathered back and had a chance to organize themselves. They were then standing in random positions in the room. Their physical location is explicitly pointed out to them while the network is still working, making them aware of that the network is actually working fine and as a ring (or star) while they themselves are not standing in such a manner. The participants are then encouraged to position themselves in the corresponding physical locations (i.e. ring or star) so that the network becomes visible and apparent in how it passes packets around, lighting up LEDs on the node that has it. This distinction is simple but important to know when facing a choice between topologies indirectly through choice of radio technology.

These three inspirational bits can help both us and others to understand the concept of topologies and also show how something as 'immaterial' as how the nodes are set up to communicate can be used to unfold the design space. By using these bits ourselves we got a better understanding of what happens when a node for some reason fails. For instance, how it is that the star topology is more robust than the ring in case of failure, but also how fragile the star topology is when something happens to the master node.

Having this knowledge allows for more informed decisions, when prototyping or implementing various designs using radio, e.g. choosing ZigBee over Bluetooth because of network setup latency. Seeing how a star topology handles node failure also gives a better understanding for what can happen in e.g. Bluetooth networks. Finally, by making both designers and engineers working together in a multidisciplinary design team aware of these matters, designs that cope with various communication problems explicitly, or use such failures as a resource for something else, can be created.

In summary the most important aspects of radio that were explored by these Inspirational Bits were:

- ComNet – shows how the packet passing order differs between network topologies and how that can affect the user experience.

- RobustNet – shows how topologies differ in terms of robustness and what happens when something goes wrong.
- GeoNet – shows how, in wireless communication, the physical placement is different from the logical positions that stems from the topology, e.g. ring or star topologies

CONCLUDING REMARKS

In conclusion, we have presented our work on radio as a design material within the field of interactive systems design, and how we see from our work on the LEGA system and other projects that there needs to be a shared understanding about the radio material among all professionals working in this area in order to work better together and create more innovative designs. We have also argued for the need of better tools for turning immaterial materials such as radio into useful and understandable resources for designers and engineers alike. Here we have specifically focused on radio and the Inspirational Bits approach, but there are some efforts addressing the same issues albeit in a different vein (e.g. [13]) and of course many other materials.

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