Network Visualisation

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Abstract— Todays network managers and system administrators are challenged by a rapidly growing mass of status information and an increasing volume of data sent through networks. Analysing this data can reveal weaknesses in the performance and security of the system. Performing this task with text-based tools in real time is slow,difficult and inefficient. Preventing overloads in the capacity of connections or taking immediate action on possible attacks is almost impossible, without spending an inappropriate period of time. Network visualisations are powerful if basic rules of data illustration are considered and the information is well prepared. Implementing effective filters, as well as aggregating and averaging information, can reduce the data volume strongly and help to gain a mental map of the network administrators have to manage. Nevertheless, details should be available depending on the users demands. Visualisation tools should support the user in fields of security handling, flow monitoring and the status of the system. Monitoring the system is often only one out of many daily tasks of an (system or network) administrator. Alternative monitoring methods with sound or ambient illustrations can keep the network administrators informed but offer the possibility to focus on other tasks at the same time.

Index Terms—Network, Visualisation, Data

1 Introduction

Nowadays, information becomes one of the most important values for companies and is stored more and more often digitally, instead of being archived as printouts or hardcopies. As the data volume is shared all around the world on different locations and is linked together in networks, the managers and administrators of these connection gain importance too. The Internet as the biggest data network of the world is the backbone for almost every flow of information around the world.

As well as the global wide area network, almost every company, from smaller mid sized ones up to global players, store, change and exchange their business data throughout local area networks. Similar to the increase of the meaning of digital data sharing, other aspects like data availability and security get more important as well. Administrators need to keep the network stable and need to know what is happening in their field of responsibility at all time. Tools to help managing massive data volumes often face themselves with different problems on two levels. On the first level, information which has already been stored or appears constantly has to be filtered, aggregated and averaged. After this step of preparing the data, the problem of implementing useful visualisations arises[2].

Even a massive number of collected data is useless without giving a meaning to it. The visualisation of network data is the interface between the administrator and his working surroundings. If the visualisation considers general rules of data illustration, graph theories and offers the user the possibility to specify his own demands on what to be shown, then the program can really help to manage the network.

2 General visualisation

The interface to represent stored data (for example on a pc, apple or other electronic devices) and the human brain are visualisations. Information has to be transformed to make it adaptable for the human's natural visual capabilities [6]. Effective visualisations aim on fast and simple possibilities to access massive data volumes in order to read, edit or analyse. The representation of data, gained in the medical sector by computer tomographs, would be useless without the right transformation into a visualisation. After preparing this information, the medic can combine his knowledge with the produced data and make his decision [15]. This example also shows the need of a simple and rapid representation of the given data.

In order to represent the data to be displayed in the right context, it is necessary to categorize them first. Information can be divided into different types. These types of information vary due to dimensional and environmental factors. On the other hand there are various types of visualisation techniques that can be used [10].

Depending on what the visualisation should represent and how data was collected, not all possible combinations are effective and useful for the user [17].

2.1 Type of data

The status of real life objects or man-made data structures is defined by the value of its attributes. According to the complexity of the object, the number of attributes can vary from just one, up to an almost infinite count of describing qualities. The following categorisations are based on [10] and [21].

2.1.1 One dimensional

Information representing the situation of an object without any connections to other factors like time or local position (for example name or serial number).

2.1.2 Two dimensional

Two factors define the status of this information. Only one part of this date is not enough to get the exact representation. Coordinate systems with two axis are the most common way to display this type of data (for example 2D geographic location shown on a planar map).

2.1.3 Three dimensional

Representations of a two dimensional datasets with changes over time are the most common type of three dimensional data structures..

2.1.4 Multi dimensional

In multi dimensional data, time is often an important value to show changes of other factors. The actual status of a specific object is defined by the status of all values available. An example for this type of data could be the change of position in a three or four dimensional space according to transformations in time.

Often the information is created in structures with a high level of complexity and the dimensions rise with every factor.

2.2 Type of technique

There are many different ways to visualise given data. The realisation of one of the different options often depends on the data volume and the aim the visualisation should have on its viewers.

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- *This research paper was written for the Media Informatics Advanced Seminar on Information Visualisation, 2008/2009*

2.2.1 Icons

To represent one-dimensional data, simple icons can be used. They combine one single information with one object. This data is consistent over time.

2.2.2 Graphs and diagrams

To visualise two or three dimensional data mostly graphs are used. Graphs are best in showing the change of a value within time. There are different possibilities to convert actual values into graphical objects. Common types of graphs are columns, pies, globes or simple lines *(see figure 1)*.

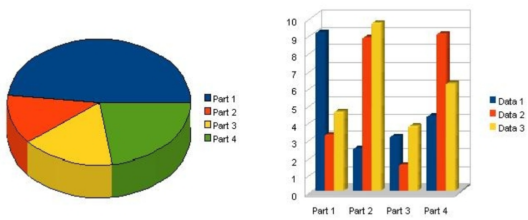

Fig. 1. Simple pie and column graph , Source: Sun OpenOffice

2.2.3 Contour plots

Contour plots can optionally combine single values of a three dimensional data evaluation, such as geographic landmarks, to an interpolated but closed 3D-layer.

3 General network visualisation

3.1 Definitions

To set a working ground and to avoid misunderstandings, this section defines some basic terms. Topics for this terms are graph theories and network structures. This section is based on definitions from different resources and combines them to one dataset [16], [23].

3.1.1 Network

A number of computers connected and interacting in order to exchange informations, share performance or monitor actions taking place on remote devices.

3.1.2 Nodes or vertex

In the graph theory a node or vertex is an atomic unit a graph is built of. Nodes can illustrate objects within the dataset. The information behind a node can be very complex, but is often reduced to simplify the view.

In a visualisation of a network, these nodes can be hardware components, such as routers, switches, servers, end-user-pcs or even stand for another complex network, or parts of it.

3.1.3 Links or edges

Nodes of a graph are connected via links. These links display any kind of a relationship between the vertices they associate. Depending on the type of connection, the link can be valued or directed. There might be only a dependency from one node to the other (uni-directed), or represent a relationship involving both directions (bi-directional).

In terms of data-networks, links show actually existing connections between the network components. These connections are often categorised by the technically possible data volume transported over a specific time slot (bandwidth). Another possible determination can be the way data is send through a network (for example optical or electrical). The visualisations of these connections are often used to display information about the data that was sent between the nodes, like data volume or used protocols.

3.1.4 Graph

A graph consists of a set of nodes and edges. Depending on the connection between the nodes, there are different types of graphs:

- Complete graph: In a complete graph, also called universal graph, the proportion between nodes an edges is predefined. The number of edges is $\binom{n}{2} = n(n-1)/2$. It is written: K_n
- Circle graph: In this graph the edges link the nodes in exactly one circle. An abbreviation for this type is C_n

3.1.5 Graph specifications in networks

Network structures as real life transformations of mathematical graph-theories, appear in different types of topologies. The configuration may represent one single graph-type or a complex structure as combination of miscellaneous variations *(see figure 2)*.

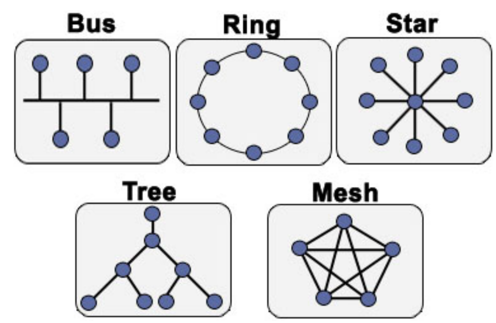

Fig. 2. Different types of topologies Source: [11]

Bus Topology Based on one backbone wire, the bus topology uses this medium to connect all linked devices. To send data to one specific host, the message has to be broadcast all over the network. Only the addressed host will accept and threat this connection. Disadvantages of this type of topology are the dependency on the backbone as well as the security issues of sending a message to a complete network which perhaps should only be read by one host. Another problem is the usage of the backbone as one single shared medium, so the bandwidth as to be split up to the connected devices. This topology can be used for small networks, but loses its advantages of being easy to install and maintain, if the size of the system grows.

Ring Topology The shape of a ring topology is always a closed circle. Every device in this network is connected to two neighbours. The data is send either clockwise or anticlockwise through the network. The basic type of this network is self-managing which means there is no need for a central controlling unit. Every host has the same possibilities to send data across the ring. Based on the structure of this network one big disadvantage is the harm of the complete network if just one single connection between two hosts breaks down. Another problem is the enlargement of the system. By adding another host to the network, the circle is interrupted for a certain time.

Star Topology Based on a central managing node, all other members of the network are connected to this main device. This controlling host can be active, like a router or switch, or passive like a hub. In a star topology with a passive central node, every message is broadcasted to all connected members. If the managing node is active, after a certain period of time or a certain number of sent packages, the host router or switch can delegate the messages so that the traffic volume is reduced and a security advantage is gained. In comparison with the bus or ring topology, this kind of network is not that fragile regarding the failure of single hosts. Messages can still reach the other parts of the system. The disadvantage of this topology is the dependency on the central managing node. If this part of the network breaks down, the entire communication collapses.

Tree Topology This topology combines both, the bus and the star topology. A tree network is built on a hierarchical structure. The first level is defined by the root node. Hosts connected to this root establish the second level. Every node can just be connected with one node from a higher level, but multiple nodes from lower levels. A true tree topology begins on level three. Before this, the network exhibits the attributes of a star topology. Starting on level three, this type of network represents a bus system of star topologies.

Mesh Topology This form of topology combines all different types of topologies. Some parts of this network can be connected as a star, other parts as a ring, bus or tree. The separate segments are linked together via routers or other uplink capable devices. This type of topology represents for example the structure of the Internet, with thousands of subnetworks with different types of configurations.

3.2 Perception rules

"The whole is more than the sum of the parts". According to this aspect, looking at one single node reduces the information a visualization can present the viewers. To moderate connection, relations and meta informations of the network, specific rules have to be fulfilled [18]. According to E.Goldstein seven perception rules have to be considered [8].

- The Law of Simplicity
- The Law of Familiarity
- The Law of Similarity
- The Law of Good Continuation
- The Law of Proximity
- The Law of Common Fate
- The Law of Connectedness

Considering this rules allows the user to build up a mental map of the network and remember the different parts even throughout animations or rotations of network-visualisations.

4 AIMS OF NETWORK VISUALISATION

Because of the of the great amount of confusing textual data, produced by even small networks, visualisations are essential to retrieve fast and easy access to different aspects of the network. User studies [9] [1] involving high skilled system administrators as well as lower skilled daily pc users, show that a good visualisation can reduce the requirement of previous knowledge to gain a well formed overview of the actual status and perhaps make a simple analysis of already collected data. In most cases monitoring a network sets the focus on three main aspects: flow monitoring, security and the status including the topology. As most network visualisation programs cover the most common aspects the user wants to know, it is not only necessary to provide information for only one view, but to transfer it also into the other parts of this program. So called "mental maps"[18] should be created. Mental maps allow the user to easily discover parts of the network presented in one view, over the whole program. If for example a leak of connectivity is discovered in the flow monitoring view, the parts of the network which are involved should be detected in a very fast and easy way.

Another basic rule which should be considered is the mantra published by Ben Shneiderman: Overview first, zoom and filter, then details-on-demand [21]. The technical opportunities to display data with the pc have constantly grown over the past years. The size of the screen, higher resolutions and other developments made it possible to display vast data volumes at the same time. This possibility can lead to an overload of information the user can not handle any more or which would take to much time to assimilate. Even though the human perceptual abilities would be able to handle this quantity of displayed data, it would reduce the aim of providing quick and simple access. To avoid this failure the mantra begins with the overview. This overview should give the user the possibility to discover major aspects of the given network. That could be the size of the components, overall traffic volumes, number of connections or attacks occurred in the past few hours. Based on these vertices the user can decide whether this information is enough or if he wants to take a closer look. This is the second part of the visual information seeking mantra: zoom and filter. Effective filtering is an essential part to reduce the quantity of data, which is available but uninteresting for the user's goals. These options of interest have to be discovered by the ones who develop the visualisation and should contain basic properties of the given topic. If these options are well chosen, even rather unskilled users could gain access to deeper levels of the system without being overwhelmed by the mass of information.

Gadgets allow them to set the focus and adjust the zoom factor. To retain the point of interest the zooming should be smooth and easy to modify. How to set the focus can vary from program to program. Selection parts of the system by raising a rectangle or just pointing the mouse on the field of interest and pushing a button are just two possible options. The last part of the mantra, details-on-demand, is necessary to give the user the opportunity to extract important data, which might be uninteresting in most cases, but maybe crucial to solve fundamental problems the user has to handle. Depending on the zoom level, the details can be shown already or appear if the user demands them.

4.1 Flow monitoring

As most networks consist of different types of components and offer different users an interface to other parts of the mesh, data flow is not homogeneous across all connections.

Analysing graphs, produced by flow monitoring tools, can outline the appearance of undiscovered overloads or disclose illegal or unauthorized access out of the network or into it. Based on this information, components can be exchanged to eliminate bottlenecks or more efficient connections can be established.

4.2 Security

From personal data stored on a pc in a home used network, to high confidential information of a worldwide interacting company, security is one of the most important issues for those who are responsible. Global spreading worms, destructible viruses and malicious software disguised as trojan horses are just a small extract of what administrators or simple home computer users have to deal with.

Monitoring, analysing, diagnosing and responding [9] can reduce the possibility to be the victim of an undiscovered attack on the system. Unfortunately creating pattern, close weak spots and teaching users in the handling of suspicious software can not eliminate all possible intrusions into the data network. Not until the combination of an easy to monitor and fast adjustable software to visualise data emerging, with an aware administrator, the network becomes adequately safe.

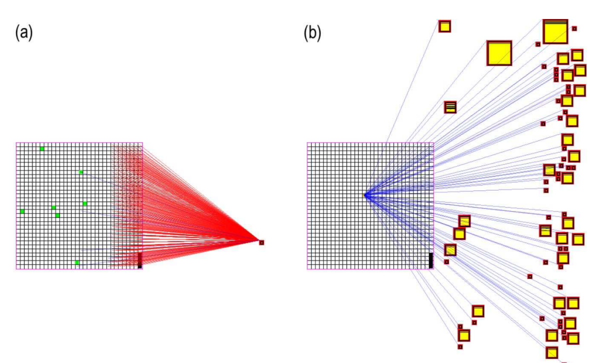

Fig. 3. Matrix Visualisation: HomeCentric Visualization of Network Traffic for Security Administration (Ball R. ,Fink A., NorthC.). (a) fan-in, (b) fan-out

Different types of patterns are used to discover possible attacks or misuses of the network. Finding these structures with text based managing tools is often inefficient. With visualisations like figure 3, even unskilled users can identify these patterns without spending too much time. Picture (a) shows a ping sweep executed by an external host on computers of the network of interest . Figure (b) displays a fan-out, which means that an array of external hosts receive data from a computer of the home network. This computer could be a web- or file-server, offering data on the Internet.

4.3 Topology

The status of a network always depends on the situation of every component of the system. Losing one single router can harm the infrastructure or the usability of the whole network, as well as the breakdown of a fileserver. To keep every information available at all time is necessary for permanent data access for business companies all around the globe. Simple visualisation, made out of icons and images, can represent the structural layout of a network topology as nodes and links and help users to gain quick access into the hierarchy and the location of possible malfunctions or leaks. It can be also a useful tool to analyse the structure in order to optimize links and positions of components of the network. Topology illustrations can help to decide about further decisions like changes, extensions or complete reorganisations for parts of the system.

5 Specific network visualisation techniques

5.1 Flow visualisation

Which parts a network appear a flow monitor can diversify from only one connection between two hosts or represent an overall capacity utilisation throughout the whole system. Also important of what to be displayed is the zoom the user wants to use on the given data. Is it enough to show just the bandwidth or is it necessary split the data up on the level of used protocols.

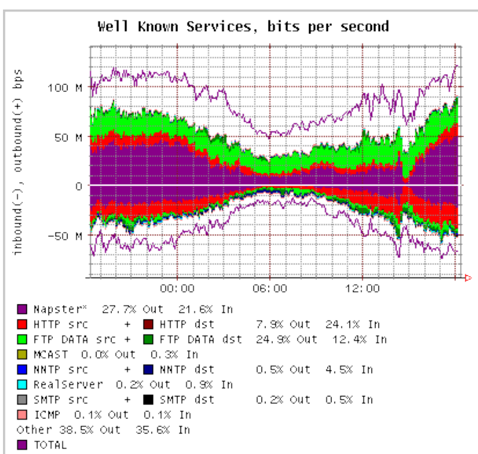

Fig. 4. Flow Visualisation: A Network Traffic Flow Reporting and Visualization Tool (Plonka D.) network usage of the University of Wisconsin-Madison

This graph *(see figure 4)* shows the load of the network capacities of the University of Wisconsin-Madison for the period of 24 hours. The upper part represents the outgoing data, the lower part the incoming. The colour-coding is used to separate the different types of protocols. This view centres the users focus to the data that was sent within the network. A possible drawback could be the blank out of overall relationships [20]. Embedding flow visualisations into topographical maps of the network, facilitate the understandings of circumstances of data appearance [2]. Associations between traffic and the connected nodes are preconditions to perform appropriate analysis.

5.2 Network topology

Topology visualisations represent a simplified overview of a network's structure. Devices of this system can be drawn as icons or already display different facts of this component. Depending on the size of the network, as well as the zoom level, parts of the network can be merged and details are only visible if the focus gets closer. Some visualisations are only used to provide a quick and simple image of the network and only few details are displayed. This type is often used to present the structure of the system, describe the size and perhaps the local position of the components. Zooming is usually only available for levels with less details.

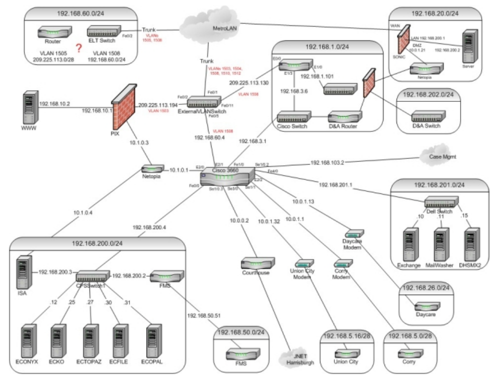

Fig. 5. Topology visualisation with device illustrations. Source: [24]

This topology *(see figure 5)* shows the simple representation of a given network. Different types of devices are displayed with separate icons depending on their function. Additionally the IP address is shown for every host. The basic structure of this system is the star topology with a router as the managing node. Other subnets can exhibit own network managing principles. Drawing the components with simplified representations of common network components allows a quick structural analysis of the design and a fast identification of important components.

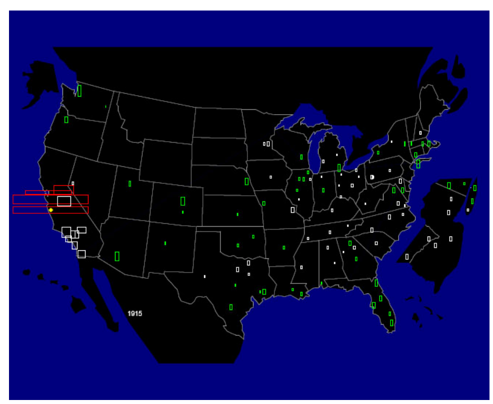

Fig. 6. Topology visualisation with geographic surface Source: Visualizing Network Data (R.A. Becker, S.G. Eick, A.R. Wilks)

Topology illustrations, based on well-known surfaces like geographic maps, offer the users a possibility to easily apply previous knowledge onto the structure of the network. Figure 6 shows the traffic capacities of a telecommunication network. As the nodes are place on the map according to their real geographic position, users do not have to know specific descriptions or analyse complex textual data to become aware of the actual network status and the relationship between the individual devices. Are the traffic hot-spots allocated or are they locally constricted? Such details would only be hard to discover and would cost lots of time for someone looking at the statistics of this network.

5.3 Matrix visualisation

The identification of components in the network is usually done by the Internet Protocol address. This unique number consists of several parts and makes it possible to identify different properties combined to this segment.

5.3.1 Matrix Visualisation by VISUAL [1]

The design of the visualisation tool VISUAL is based on the division between the home-centric and the external perspective of the network. Core-element of this application is the representation of the internal network as a matrix. Every host of the system is represented as square within the grid. To recognise the different hosts, the position inside the matrix, as well as the position for external devices around the matrix, is defined by their IP address. To reobtain a constant position for external devices, the first 16 bits of the address are used to set the X-, the last ones to set up the Y-coordinate. Based on this technique, administrators can simply identify subnetwork patterns, according to close local appearance on the display. Main attention is drawn on the connections bridging both parts of the network. Depending on the data-volume sent between the external host and members of the internal system, the size of the marker is adapted. This feature allows the user to identify and monitor devices with high activity to prevent possible attacks on the system *(see figure 7)*. Connections between two host are displayed as coloured links. Following Shneiderman's mantra [21], additional details of the connections are displayed on the right side of the screen. This information can either be the used protocol, IP-addresses of both hosts or the amount of data exchanged as well as the time of observation.

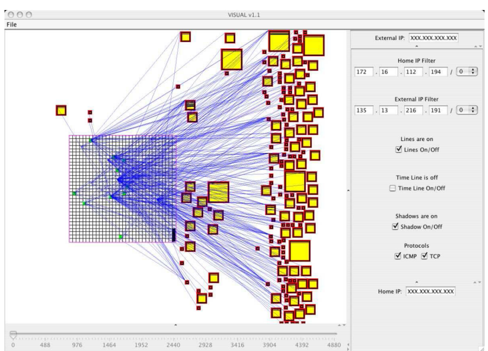

Fig. 7. Matrix Visualisation VISUAL: HomeCentric Visualization of Network Traffic for Security Administration (Ball R. ,Fink A., NorthC.)

5.3.2 Matrix Visualisation by SeeNet [2]

The aim of this matrix visualisation is to focus on the links between the nodes of the network. Hosts are listed as indices on both sides. In this case we only take a look at uni-directed connections. The top indices represent the components where data was sent and the indices on the left show the ones who received them. Due to the fact that not every host is listed on both sides, this could lead to a N,M matrix. The data volume is represented as a coloured dot. Depending on the value the colour changes from green, only few data, to red, many transferred packages. This visualisation allows the user to quickly analyse in how many connections a host was involved, by just looking at its column. The number of connections and the value of transmitted data can indicate whether this host only tried to simply communicate with another host or maybe harm parts of the system. But not only uni-directed connections could be represented. Likely to the indices of the first visualisation, every single one represents a host operating in this system. But instead of only listing the ones sending data on the top side of the matrix, and the destinations on the left side, every host is mentioned in both lists. Depending on the regulations, the upper or lower triangle matrices is used to display data which was sent or received. This makes it possible to analyse whether a host was rather passive, like a server, or active by trying to gather great values of data from different hosts. This diagram *(see figure 8)* shows a matrix visualisation with data from the AT&T Long Distance Network. The information represents data exchange after an earthquake that occurred in the San Francisco Bay area, on October 17. 1989. The graph of this network is nearly complete and consists of 110 nodes, mostly switches. New status reports were collected every 5 minutes. According to their geographical position, the nodes are listed from west-to-east. The intersection, drawn as a dot, between two nodes represents a connection and the colour indicates the load. The analysis of this matrix shows that five nodes exhibit the most traffic. Due to the arrangement of the nodes from east-to-west it is obvious that these nodes represent the parts of the network which were directly located in the affected area.

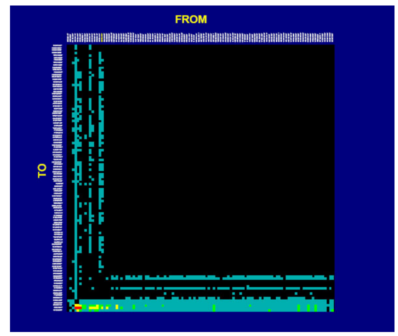

Fig. 8. Matrix Visualisation NetViz: Visualizing Network Data (R.A. Becker, S.G. Eick, A.R. Wilks)

6 Alternative methods for monitoring

Although the interaction between users and a computer are mostly reduced to standard devices like monitor, mouse and keyboard, other interfaces are also possible and are already in use to support and help [12]. Nowadays, the functions of system administrators are widely spread and multitasking is daily business. To make it easier to handle different problems at the same time, alternative ways to provide information are used.

6.1 Mobile network monitoring

To be competitive and to reduce the possibility of performance leaks, network administrators have to be aware of the companys system-status at all time. Even short breakdowns of the website, online-shop or web-services can cost a lot of money or the customers reputation. With new developments in the hard- and software of mobile devices, administrators can now be informed of the status independent from time and locality. New network monitoring software offers the users the possibility to access webservices which were designed to display major information on mobile devices *(see figure 9)*. Based on this information the administrator can decide which actions have to be performed, without being even close to his desktop [22]. Fast decisions safe money and can reduce the impact of malfunctions for the company.

6.2 Sound monitoring with NeMoS[14]

Network monitoring via sound was already realized in other programs like SoundWIRE[3] or Peep [7]. These programs offer the user possibilities to monitor parts of the network and receive the status as an audio output. Simple implementations produce for example an intuitive knocking sound when someone logs on the server[5]. Producing sounds when activities occur can draw off the attention of people using this software, although the cause for this distraction was not so important.

The goal of NeMoS was to represent the status of a complex system with a continuous surrounding sound atmosphere without annoying the user but demand the attention of the administrator if something important happens. The architecture of this software is client server

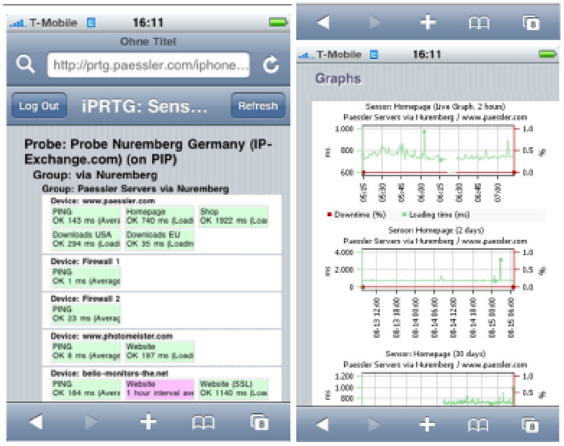

Fig. 9. Webinterface designed for mobile devices (Source: [19])

based. Every client can be adjusted separately and collects the activities produced by the host the daemon is executed. This information is send to the server, where every client is registered. The server manages all connections to the clients and reallocates the data. With this structure every host logged into the server can be used to monitor the whole system. The information-exchange about the status of the components is based on the Simple Network Management Protocol (SNMP) and the software is written in Java. To reach the aim to not annoy, the user can compose channels build of MIDI tracks to reflect activities. Each channel represents a part of the network, so that they can be perceived separately. If an activity takes place, multiple layers of the MIDI-parts overlay and the volume increases to gain the attention of the administrator. This method prevents a prompt interruption if it is not necessary but informs the user appropriately.

6.3 Ambient visualisation or when monitoring becomes art

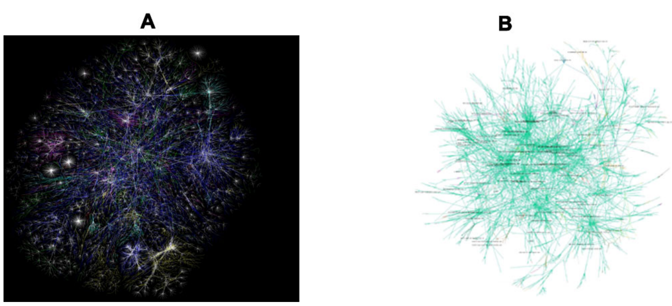

Fig. 10. Illustrations of the Internet (Source: (A) [13], (B) [4])

The size of a network, the data volume or the number of layers to visualise complex information structures, make it difficult to filter or to sum up data, produced by or are used to describe a network, in an appropriate way. Analysing this data can be very time consuming. Like already mentioned in chapter 6.1 monitoring the network status is just one out of many tasks an administrator has to fulfil. Alternative ways of visualisations can be useful to integrate information into the working environment without being too obvious and too distracting. Sometimes only few facts can be necessary to be sufficiently informed. This information can be presented as simple colouring of a picture or ambient illumination. At this point, network visualisation can become art. Illustrations of for example network structures or data flow in which the actual content becomes secondary, can be seen as abstract art or by-product that still contains enough information for someone who knows what to look for. This diagram *(see figure 10)* shows some illustrations of the Internet. You can see abstract visualisations without communicating any real information.

7 Conclusion

The appearance of great data volumes produced by network monitoring and managing tools, make it necessary to transfer this information via an interface a user is able to absorb in an adequate period of time. Many programs are available to implement different types of visualisation techniques which can solve this general problem. Depending on the type of task the network manager has to handle special methods can be used to prepare the information. Filtering data, that might confuse or distract the user, is almost as important as an illustration of the system which should be understood easily and quickly. The detection of intrusions or misuse with textual based tools is often not possible until the users are long trained and already well informed about problems occurring in a network. Associating visual information about the system directly to several devices or associate performance leaks with parts of the environment, can reduce the time to correspond, for untrained users as well as for trained ones. Visualisations as abstractions for complex data structures have to follow certain rules in order to represent relationships, associations or local circumstances corresponding to their real life situation. Likewise, mathematical laws and algorithms were developed to optimize expositions of data structures and make them capable for the human visual perception. Sometimes visualisations can cross the line between information transfer and the utilisation of the available data and possibilities given by today's computer hardware. Not every possible representation is useful but sometimes the result can turn out to be a small piece of art.

References

[1] R. Ball, G. Fink, and C. North. Home-centric visualization of network traffic for security administration. In *Proceedings of the 2004 ACM workshop on Visualization and data mining for computer security*, pages 55–64. ACM New York, NY, USA, 2004.

[2] R. Becker, S. Eick, et al. Visualizing Network Data. *IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS*, page 1628, 1995.

[3] C. Chafe and R. Leistikow. Levels of Temporal Resolution in Sonification of Network Performance. In *Proceedings of the International Conference on Auditory Display*, pages 50–55, 2001.

[4] S. Coast. Ip mapping. http://www.fractalus.com/steve/stuff/ipmap/, 2001.

[5] J. Cohen. Monitoring Background Activities. In *SANTA FE INSTITUTE STUDIES IN THE SCIENCES OF COMPLEXITY-PROCEEDINGS VOLUME-*, volume 18, pages 499–499. ADDISON-WESLEY PUBLISHING CO, 1994.

[6] N. Gershon, S. Card, and S. Eick. Information visualization tutorial. In *Conference on Human Factors in Computing Systems*, pages 149–150. ACM New York, NY, USA, 1999.

[7] M. Gilfix and A. Couch. Peep (The Network Auralizer): Monitoring Your Network With Sound. In *Proc. LISA-XIV*, 2000.

[8] E. B. Goldstein. Brooks/Cole Publishing, 1999.

[9] J. Goodall, A. Ozok, W. Lutters, and A. Komlodi. A user-centered approach to visualizing network traffic for intrusion detection. In *Conference on Human Factors in Computing Systems*, pages 1403–1406. ACM New York, NY, USA, 2005.

[10] D. Keim. Information Visualization and Visual Data Mining. *IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS*, pages 1–8, 2002.

[11] Learn-Networking.com. Guide to network topology. http://learn-networking.com/network-design/a-guide-to-network-topology, 2008.

[12] D. Lunney and R. Morrison. High Technology Laboratory Aids for Visually Handicapped Chemistry Students. *Journal of Chemical Education*, 58(3):228–31, 1981.

[13] B. Lyon. The opte project (mapping the internet in a single day). http://www.opte.org/maps/.

[14] D. Malandrino, D. Mea, A. Negro, G. Palmieri, and V. Scarano. NeMoS: Network Monitoring with Sound. In *Proceedings of the 2003 International Conference on Auditory Display, Boston, MA, USA, July*, pages 6–9, 2003.

[15] B. McCormick. Visualization in scientific computing. *ACM SIGBIO Newsletter*, 10(1):15–21, 1988.

[16] B. Mitchell. Network topologies. http://compnetworking.about.com/od/networkdesign/a/topologies.htm.

[17] J. Moody, D. McFarland, and S. Bender-deMoll. Dynamic Network Visualization 1. *American Journal of Sociology*, 110(4):1206–1241, 2005.

[18] K. Nesbitt and C. Friedrich. Applying Gestalt principles to animated visualizations of network data. In *Information Visualisation, 2002. Proceedings. Sixth International Conference on*, pages 737–743, 2002.

[19] Paessler-AG. Prtg network monitor. http://www.de.paessler.com/e521/e1619/e1871/e2094/, 2008.

[20] D. Plonka. FlowScan: A Network Traffic Flow Reporting and Visualization Tool. 2000.

[21] B. Shneiderman. The eyes have it: a task by data type taxonomy for informationvisualizations. In *Visual Languages, 1996. Proceedings., IEEE Symposium on*, pages 336–343, 1996.

[22] C. Twardawa. Netzwerk-Monitoring goes Mobile. *network computing*, 10, 2008.

[23] E. W. Weisstein. Complete graph. http://mathworld.wolfram.com/CompleteGraph.html.

[24] WikiMedia. Dhs network topology. http://upload.wikimedia.org/wikipedia/commons/8/84/, 2008.