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1 Project title

Quality of Service for Personal Networks at Home (QoS for PN@home)

2 Participants

Scientific Staff:

- *Project leader:* Prof. dr. ir. I.G. Niemegeers, Wireless and Mobile Communications, TU Delft,
- Dr. A. Lo, Wireless and Mobile Communications, TU Delft
- Prof. dr. ir. P. Van Mieghem,
- Dr. R.J. Boucherie, Stochastic Operations Research, Universiteit Twente
- Dr. J.L. van den Berg, Stochastic Operations Research, Universiteit Twente
- Prof. dr. ir. B.R. Haverkort, Communication Systems, Universiteit Twente
- Dr. ir. S.M. Heemstra de Groot, Communication Systems, Universiteit Twente
- Dr. ir. G.J. Heijenk, Communication Systems, Universiteit Twente

Junior researchers:

- One PhD student at Wireless and Mobile Communications, TU Delft, supervised by Lo and Niemegeers
- One PhD student at Network Architecture and Services, TU Delft, supervised by van Mieghem
- One PhD student at Stochastic Operations Research, Universiteit Twente, supervised Boucherie and van den Berg
- One PhD student at Communication Systems, Universiteit Twente, supervised by Heijenk and Haverkort
- One PhD student at Communication Systems, Universiteit Twente, supervised by Heemstra de Groot and Niemegeers, TU Delft

3 Goal

Personal Network (PN) is a new concept (Niemegeers and Heemstra de Groot, 2002) related to the emerging field of pervasive computing that extends the concept of a Personal Area Network (PAN). The latter refers to a space of small coverage (less than 10 m) around a person where ad hoc communication occurs, typically between portable and mobile computing devices such as laptops, personal digital assistants (PDA), cell phones, headsets and digital gadgets. A PN has a core consisting of a PAN, which is extended on-demand and in an ad hoc fashion with personal resources or resources belonging to others. This extension will physically be made via infrastructure-based networks, e.g., the Internet, an organization's intranet, or a PN belonging to another person, a vehicle area network, or a home network. The PN is configured to support the application and takes into account context and location information. The resources, which can become part of a PN, will be very diverse. These resources can be private or may have to be shared with other people. They may be free or they may have to be paid for their usage. Figure 1 shows an example of a PN.

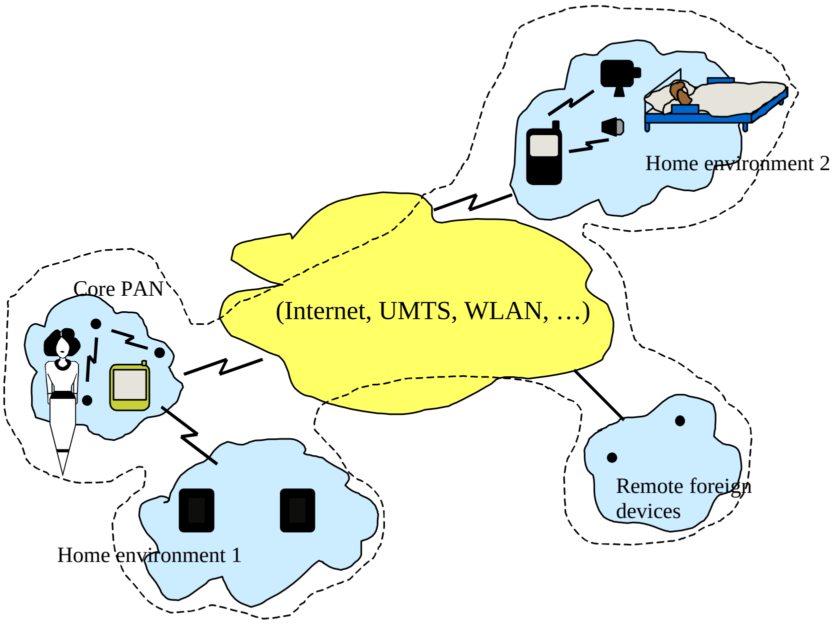


Figure 1: Example of a Personal Network

This project focuses on QoS in PN's in the home environment. The objective of the project is to investigate and develop solutions for establishing personal networks that are able to support QoS in a fast changing environment.

The concrete objectives of the project are the following:

- Proposal of suitable architecture(s) for PNs.
- Solutions for context and resource discovery.
- Development of solutions for self-organization and self-configuration of PNs.
- Understanding, methods and techniques for QoS routing in dynamic and heterogeneous environments and end-to-end QoS provisioning.
- Investigation of the implication of the proposed solutions on implementation aspects such as complexity, power consumption, scalability and performance.

4 Innovation

The project targets research that is globally considered as a focal point in communication networking. The main reasons are (a) the high business potential of PN concepts and (b) the scientific challenge of proposing dynamic (i.e. time-dependent) network solutions. While the first business motivation hardly deserves further elaboration, the second scientific reason needs some additional explanation.
Current networks such as the Internet and wireless networks already contain some level of time-dependent adaptation, but many consider this level as far insufficient because resource dependent networking is largely lacking: mainly connectivity is currently provided without multiple levels of quality of service (QoS). Moreover, a seamless interoperability of different networks and protocols still remains a great challenge. Finally, while QoS is generally agreed to be desirable (also from a business perspective), QoS-aware network architectures in Internet-based environments are emerging slowly, most of them as overlay networks over a QoS-unaware technology. In these architectures, QoS is considered as an add-on rather than embedded as a design principle (as in ATM) which may explain the almost absence of levels of QoS in data networks. QoS affects many different layers in the protocol stack and is hard to provide as overlay construction.

The specific target of this proposal lies in the combination of a QoS-aware network architecture for PN in the home environment and the performance/feasibility of such QoS-aware PN's. The scheduled results of the project are twofold. First, the architectural study will be tested by building a prototype small PN. Second, new insights in design, control and dynamics of QoS-aware PN@home will be disseminated via papers and communicated to the contacts in the industry (see next section).

In calls for large projects such as the EU 6th Framework Programme, EU Networks of Excellence and the Dutch Bsik/Freeband, similar objectives as in this proposals are pronounced. Calls for papers in international conferences additionally indicate the relevance of the current proposal.

Finally, a patent search underlines the novelty of the project in that no similar ideas are already patented and, hence, that no limiting conditions for the execution of the project exists. In the patent search, numerous patents and patent applications in the area of personal area networks, e.g., in the area of Bluetooth technology, were found. No specific ideas in the area of personal networks, and the methods investigated in this project have been found patented.

The main idea of a personal network has already been published (see Niemegeers and Heemstra de Groot (2002)) by two of the project participants, and will not be patented. If beneficial for the commercial exploitation of the project results, an attempt will be made to patent some of the specific methods that will be found in the project. Especially methods for routing, traffic management and self-organization may be patentable.

5 Technical approach

The project consists of four workpackages. The workpackages are:

- WP1: Architecture and System specification including Integration of Access Technologies
- WP2: QoS control and modeling in both traffic and routing
- WP3: Self-organization and resource discovery
- WP4: Prototype

They are described in detail in the next section.

The five phases of the project are:

- Phase I: Requirements (M0-M6)
  This phase will define the requirements of PNs in terms of functionality and QoS according to the specific aspects of home environments.
- Phase II: Analysis (M7-M12)
  This phase concentrates on the analysis of the problem with respect to the requirements that have been defined in the previous phase.
- Phase III: Exploration (M13-M24)
  This phase will define and explore different solutions. Quality criteria will be defined in order to evaluate and compare different alternatives.
- Phase IV: Refinement and prototyping (M25-M39)
  This phase will further develop and refine the solutions selected from the previous phase. A subset of the solutions will be implemented and integrated in a prototype
- Phase V: Evaluation and conclusions (M40-M48)
  Finally, this phase will evaluate the solutions in terms of the requirements defined during Phase I.

5.1 Description of the workpackages.

WP1: Architecture and System specification including Integration of Access Technologies

This work package will define the overall architecture of Personal Networks and will provide the system specification for PNs in the home environment. Further, it will address general issues like naming and addressing, seamless integration of access technologies. First ideas in this direction have been presented in Niemegeers and Heemstra de Groot (2002).

First, the concept of Personal Networks in the home environment will be elaborated. Relevant issues are:

- What abstraction can be used to model PNs so that developers and also human users can reason about a PN?
- Are current naming structures suitable for use in PNs?
- Which are the requirements on PNs in the home environment?
- Which functions need to be implemented in a PN?

Next, an architecture for PNs in the home environment will be defined. It will describe which functions can be identified in a PN, how these functions relate to each other. The architecture will structure the system, both physically and in terms of functional behaviour. This architecture defines which protocols, protocol mechanisms, algorithms, and technologies need to be developed for PNs, and how existing protocols and technologies can be integrated in PNs
Typical issues addressed at this stage are

- How should naming and addressing be solved?
- In what way should service and resource discovery be done?
- How can a PN be designed such that it is self-organizing?
- How are a users personal preference taken into account?
- How do different PNs interact and share resources?
- How can a PN operate seamlessly using a variety of different (wireless) access techniques?
- What are specifications for routing mechanisms?
- How are QoS features taken into account? What are the relevant QoS qualifiers? Is CAC needed?
- Integration with other networks, in particular the Internet:
  - Is TCP appropriate transport protocol? 'Light' TCP needed?
  - Are new, enhanced transport protocols needed?
  - Should we use concepts as virtual source and virtual destinations

In the development of the architecture complexity (cost), scalability, performance, energy consumption, and security aspects need to be taken into account.

During the course of the project, the architecture will be refined. Further, specific issues such as naming and addressing, seamless integration of access technologies, and interaction with public networks will be worked out in more detail. Note that specific issues (such as QoS aspects, resource discovery, and self-organization) are worked out in other WP2 and WP3.

Deliverables WP1:

- D1.1 PN requirements (M06)
- D1.2 Initial PN architecture (M12)
- D1.3 Refined PN architecture (M24)
- D1.4 PN architecture evaluation (M48)

WP2: QoS control and modeling in both traffic and routing
The eventual goal underlying the work proposed in this work package on QoS Control is the development of 'light weight' traffic management and routing mechanisms/strategies for Personal Networks at Home, such that:

- different QoS requirements of the various applications are met
- energy consumption (e.g. battery power) is sufficiently low
- bandwidth is used sufficiently efficient
- traffic management and QoS-routing can be performed in a distributed way

The description of the specific subjects to be addressed in WP2 are organized in the following way:

- Traffic aspects, in particular end-to-end QoS modeling and analysis, QoS differentiation and transport protocol performance.
- Routing aspects, in particular dynamic, multi-hop QoS routing

It is clear that traffic and routing aspects in PNs are intertwined, which asks for an integrated approach.

Traffic aspects
Modeling and analysis of end-to-end QoS over multiple wireless hops
Communication among diverse light-weight devices that are non-synchronised will typically result in short range transmissions (due to low energy and interference requirements) over multiple hops. Data transmissions on the same *and* on 'adjacent' links use common underlying radio resources, both at the physical layer (interference) and at the MAC layer (e.g. packets on successive links contend for the same

time slots). This yields complicated interactions between traffic flows 'travelling' through the network which severely complicates analysis of end-to-end QoS.
For the single hop case several analytical performance studies are available, see e.g. [Bianchi00], [Hazi-Velkov01]. In particular, in [Litjens et al.02] we have successfully applied processor sharing type queueing models to analyse the performance of a IEEE 802.11 WLAN at the flow level. This study provided considerable insight into the flow transfer times under random/bursty traffic conditions. Similar models have been applied in [Litjens & Boucherie] for the analysis of interfering cells in a UMTS environment that can be seen as two parallel single hop links contending for resources (spectrum). Several simulation studies consider the multiple hop case, see e.g. [Group of Gerla et al. at UCLA]. However, analytical performance models required for providing fundamental insights into the impact of the system on end-to-end QoS are not yet available. Our goal is to extend our previous work on the single hop cases to the multiple hop case. In this respect, we will focus our attention on the MAC layer of dedicated, recently developed standards such as IEEE 802.15.4. The performance models will serve as 'tools' for studying issues like scalability (what is the impact of increasing traffic load and network size on the end-to-end QoS), QoS differentiation (see below), etc..

QoS differentiation

In a network supporting various application types, QoS differentiation between the applications (e.g. through prioritisation) is an important issue. We will primarily study QoS differentiation at the MAC layer, like in IEEE 802.11e single hop WLANs (see e.g. [Mangold et al.02]), but now for the multiple hop case. The main question, of course, is *how* to realize in a distributed environment the various throughput and delay requirements of the applications to be supported. And: is the MAC layer really the right layer to achieve appropriate QoS differentiation?

Transport protocols

End-to-end data communication among the nodes of our network may be based on TCP-like transport protocols. To this end, we will investigate by analytical models and simulation the behaviour and performance of such transport protocols over multiple wireless hops, cf. [Gerla et al 1999, 2000], [Xu et al 2002]. Interestingly, TCP has been modelled in the Internet domain using processor sharing models [Roberts et al.00], [VdBerg et al. 00], so that there seems to be ample ground for integration with (and extension of) our PS models at the MAC layer. Here emphasis will be on development and performance evaluation of light weight protocols dedicated to application in PN environments.

Routing: dynamic, multi-hop QoS routing

In spite of the general consensus that future networking should be QoS-aware, hop-by-hop QoS-aware routing (as in the Internet) is still a crucial missing functionality. About three years ago, the IETF decided to abandon the QoSR working group. One of the main reasons is the fact that QoS routing is, in worst case, an NP-complete problem, hence unfeasible. This worst case NP-completeness gave rise to a large number of heuristics (Kuipers *at al.*, 2002) that more blurred the field than solved any problem (Van Mieghem and Kuipers, 2003). Recently, Kuipers and Van Mieghem (2003) have shown that, in most practical networks, this worst case scenario leading to NP-complete behaviour is very unlikely. Moreover, Van Mieghem *et al.* (2001) have proposed SAMCRA, an exact QoS Routing algorithm, and have shown that an exact algorithm (and not heuristics) are needed for hop-by-hop routing. In conclusion, the solution of the *static* QoS routing problem can be considered as sufficiently solved to be useful in practice.
The remaining issue concerns *dynamic (time-dependent)* QoS routing. In order to route in general, links in the network should be specified by (several) link weight(s) that characterize the delay, loss, bandwidth, cost, etc. of the link. Once the network topology (graph consisting of links and nodes) and the link weight structure (specification of the set of link weight vectors for each link) are known, the problem reduces to a static QoS routing problem which, as argued above, can be solved exactly. However, several questions arise:

- Which set of link weights is desirable in a (wireless) PN? How to translate data-link layer (CSMA/CA-like protocols) and physical layer (radio propagation) effects to the network, routing layer?
- How the network topology and the link weight structure be updated?
- Which nodes need to be informed (distributed or more centralized routing) and what is the scope?
- When does a node decide to trigger an update process which affects the whole network? This question clearly links traffic utilization in a node (first hop) to network behaviour.

When these conceptual questions have been answered, more practical concerns are raised such as

- What is the effect of a flooding of link state information in the network? The amount of control traffic that is superimposed to user's data traffic. If the traffic load is high, more updates are needed which cause more control traffic just in cases where increasing traffic is not desirable at all.
- What is the computational complexity to update?
- What level of uncertainty on the link weight structure is still acceptable? What levels of blocking caused by erroneous routing is acceptable?
- What is the best mechanism to flood? (via a spanning tree or hierarchical to some important nodes first who in turn distribute the information further to their adjacent nodes ?)

Applied to PNs, which are fast moving networks, an additional difficulty is that, apart from the changes in traffic utilization levels which influence nearly all link weight components related to QoS qualifiers (as delay, loss, jitter, etc…), also the network topology is constantly changing albeit on a slower time scale. Redundancy and link disjoints routing seems desirable.

Deliverables WP2:

- D2.1 State-of-the-art and recommended QoS protocols and mechanisms to be investigated (M06)
- D2.2 Assessment of proposed QoS protocols and mechanisms (M12)
- D2.3 New designs of QoS protocols and mechanisms (M24)
- D2.4 Refinement of new QoS protocols and mechanisms (M40)
- D2.5 Validation and evaluation of proposed protocols and mechanisms (M48)

WP3: Self-organiziation and Resource discovery

In order to form a PN capable of supporting a particular application with a particular quality, methods are needed for discovering what resources are available at different levels. A PN must be able, starting from its core PAN, to discover what devices, networks and services are around that it has the opportunity to link up with. This is what we call **resource discovery**.

As identified by Niemegeers and Heemstra de Groot (2002), specific questions related to resource discovery that need to be answered are:

- How should resources be characterized in terms of their functionality and their quality, such that their identities and capabilities can be communicated?

  There are two aspects involved in resource characterization: functionality and physical characteristics. Examples of functionality are: display, loudspeaker, temperature sensor, communication device, router, and data host. A device and in particular a cluster may have multiple functionalities. The physical characteristics determine the quality with which the functionality is provided (a form of QoS). Examples are: the resolution of a display, the remaining energy in the battery of a portable device, the processing capacity of a computer, the available storage capacity for hosting data, and a measure of the trustworthiness of a device.
- How can a PN find out which resources are around and available either locally or remotely?

  Two types of strategies can be considered for resource discovery: proactive strategies and reactive strategies. In a proactive strategy, a PN attempts to be continuously aware of its environment and resources are available so that when a particular application needs to run, it can immediately be determined whether this can be supported and the time needed to have the service available can be shortened. In a reactive strategy, actions are only undertaken when a particular application needs to be run. Depending on the time constants of the various processes involved, e.g., the mobility of the user, the fluctuations in radio channel characteristics, the processes of connection and disconnection of energy and cost aware devices, one or the other strategy will be better.

  The two usual techniques for discovering resources, which can in some form also be applied in PNs, are:

  - Advertising, i.e., through beacon messages, entities broadcast information about resources to devices in their neighborhood.
  - Soliciting, i.e., an entity looking for resources broadcasts a query message and gets eventually a response from devices that have knowledge about the availability of resources.

  Less common method, which may be applicable to PNs are:

- Overhearing unencrypted parts of communication between devices in the neighborhood, i.e., messages not addressed to the device.
- Combining context information with a learning process.
- "Hearsay": a friendly device or network in the device's proximity announces its knowledge about the resources that are accessible.

In general, PNs will consist of a large variety of heterogeneous entities (devices and clusters of devices) connected in an ad hoc and dynamic fashion. The state of these entities may change from active to stand-by or sleeping and disconnected during the running of applications. The constituent entities and the links that interconnect them may change frequently due to the radio link characteristics, mobility and state changes of devices (e.g., turning themselves of to save power). Access to infrastructure-based networks and servers (the Internet in particular) may not always be available or may be incidental. Under these circumstances network management cannot rely on specific functionality (e.g., such as DHCP) to be available in particular servers. The PN needs to be **self-organized**, meaning that there is no reliance on infrastructure-based servers, e.g., a DHCP server, and that there is no server functionality long-term associated with particular network entities. This is a problem, which is inherent in mobile ad hoc networks and is more severe in PNs than in PANs.

In configuring and reconfiguring a PN one can consider a number of levels of connectivity (assuming a layered architecture of a PN). The first one is at the physical and link level, the second one is at the network level, further at the distributed computing or middleware level, e.g., between distributed objects offering operating system-like generic functions, and ultimately at the application level, where distributed application entities spread over the PN components cooperate to run a particular application.

In order to establish connectivity, entities will have to use resource discovery and context discovery at various levels. Ad hoc topologies will have to be established for supporting the cooperation between distributed entities. To what extent these topologies are kept in system states will depend on the dynamics of the PN at various levels.

Deliverables WP3:

- D3.1 State-of-the-art and recommended protocols and mechanisms to be investigated for resource discovery and self-organization (M06)
- D3.2 Assessment of proposed protocols and mechanisms for resource discovery and self-organization (M12)
- D3.3 New designs of QoS protocols and mechanisms for resource discovery and self-organization for resource discovery and self-organization (M24)
- D3.4 Refinement of new QoS protocols and mechanisms for resource discovery and self-organization (M40)
- D3.5 Validation and evaluation of proposed protocols and mechanisms for resource discovery and self-organization (M48)

WP4: Prototype

In order to obtain experimental results and feedback on the implementation aspects of a QoS supporting PN, a proof-of-concept prototype will be developed.

In particular the architecture, some key concepts, protocols, mechanisms, and algorithms will be experimented with in a prototype. Prototyping will be based on state-of-the-art wireless access technologies (e.g., Bluetooth, IEEE 802.11a/e/h, GPRS), network protocols (IPv6-based) and devices (e.g., laptops or pocket PCs). A simple off-the-shelf application will be looked for, components (hardware and software) will be identified, and selected key functionalities will be implemented and experimented with.

Deliverables WP4 (prototype activities start in M12)

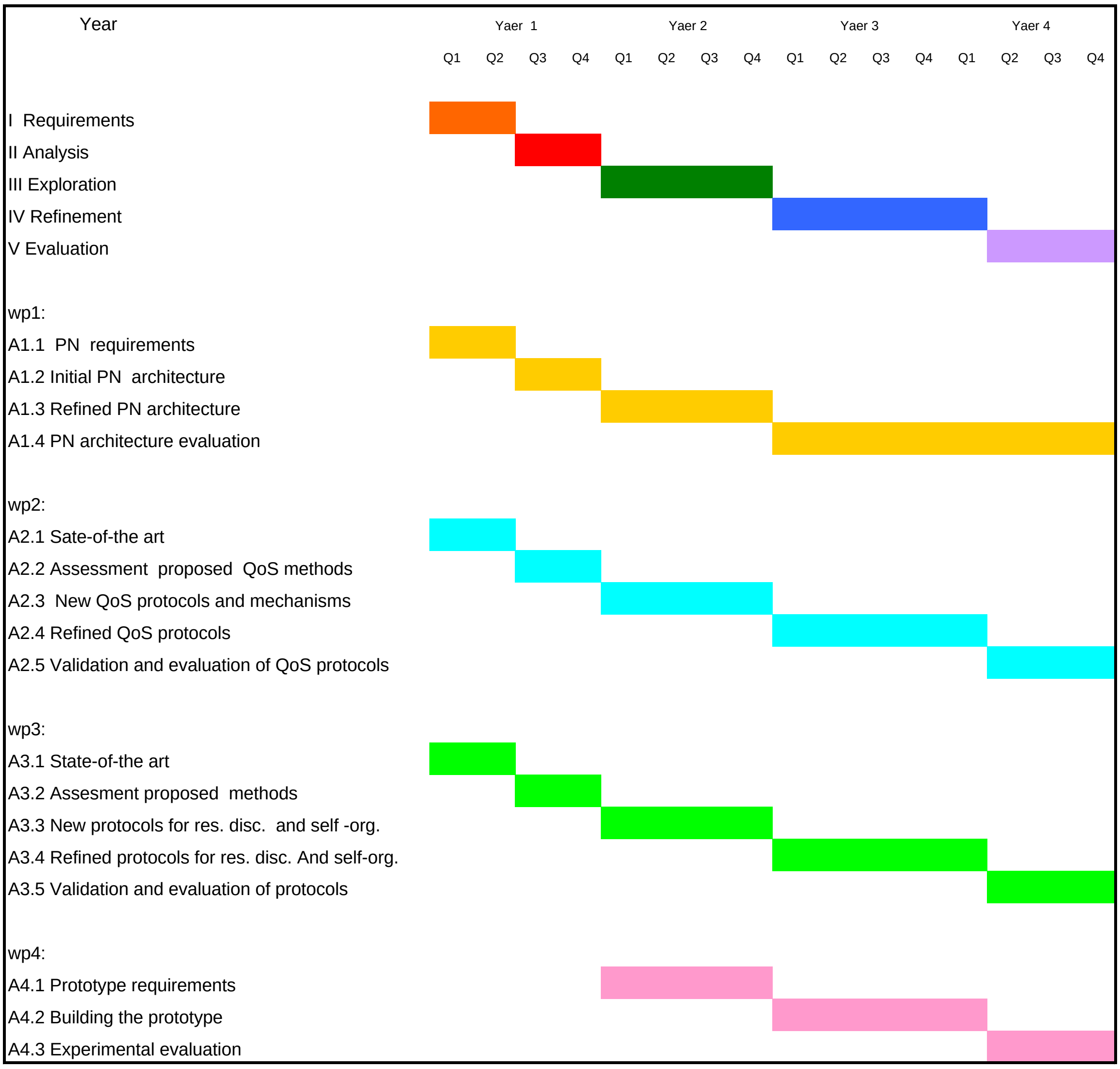
- D4.1 Specification of the prototype requirements (M24)
- D4.2 Building of the prototype (M40)
- D4.3 Experimental evaluation (M48)

6 Planning of effort and costs

The project has a duration of 4 years.
Funding is requested for

- 5 PhD students for 4 years:
  - 2 PhD students at TU Delft: TUD1 (Lo and Niemegeers), TUD2 (van Mieghem)
  - 3 PhD students at U Twente: UT1 (Heijenk and Haverkort), UT2 (Boucherie and van den Berg), UT 3 (Heemstra de Groot and Niemegeers)

6.1 Timeline of the project



6.2 List of deliverables and milestones

Month	*Deliverable/Milestone*
6	D1.1 PN requirements
6	D2.1 State-of-the-art and recommended QoS protocols and mechanisms to be investigated
6	D3.1 State-of-the-art and recommended protocols and mechanisms to be investigated for resource discovery and self-organization

12	D1.2 Initial PN architecture
12	D2.2 Assessment of proposed QoS protocols and mechanisms
12	D3.2 Assessment of proposed protocols and mechanisms for resource discovery and self-organization
24	D1.3 Refined PN architecture
24	D2.3 New designs of QoS protocols and mechanisms
24	D3.3 New designs of protocols and mechanisms for resource discovery and self-organization for resource discovery and self-organization
24	D4.1 Specification of the prototype requirements
40	D2.4 Refinement of new QoS protocols and mechanisms
40	D3.4 Refinement of new protocols and mechanisms for resource discovery and self-organization
40	D4.2 Building of the prototype
48	D1.4 PN architecture evaluation
48	D2.5 Validation and evaluation of proposed QoS protocols and mechanisms (M48)
48	D3.5 Validation and evaluation of proposed protocols and mechanisms for resource discovery and self-organization
48	D4.3 Experimental evaluation
48	PhD theses written

6.3 Effort per Workpackage (in person-months)

	TUD1	TUD2	UT1	UT2	UT3
WP1	6	6	6	6	6
WP2	0	42	14	42	98
WP3	28	0	14	0	28
WP4	14	0	14	0	14
Total effort	48	48	48	48	146

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