Abstract
The number of works addressing the role of energy efficiency in the software development has been increasing recently. But, designers and programmers still complain about the lack of tools that help them to make energy-efficiency decisions. Some works show that energy-aware design decisions tend to have a larger impact in the power consumed by applications, than code optimizations. In this paper we present the HADAS green assistant, which helps developers to identify the energy-consuming concerns of their applications (i.e., points in the application that consume more energy, like storing or transferring data), and also to model, analyse and reason about different architectural solutions for each of these concerns. This tool models the variability of more or less green architectural practices and the dependencies between different energy-consuming concerns using variability models. Finally, this tool will automatically generate the architectural configuration derived from the selections made by the developer from an energy consumption point of view.

Categories and Subject Descriptors   D.2.11 [SOFTWARE ENGINEERING]: Software Architectures

Keywords   Energy-efficiency, Software Architectures

1. Introduction
Energy-aware software development (or Green Computing [9]) is a growing trend in computing. Indeed, the increasing number of papers addressing software sustainability in last years clearly indicates that today software developer community is starting to pay more and more attention to the energy-efficiency concerns.

However, recent empirical studies [2] [12] [16] [17] show that software developers do not have enough knowledge about how to reduce the energy consumption of their software solutions. The majority of developers are not aware about how much energy their application will consume and so, they rarely address energy efficiency [16] [17]. Even practitioners that appear to have experience with green software engineering have significant misconceptions about how to reduce energy consumption [12]. Also, software developers are unsure about the patterns and anti-patterns associated to energy-efficiency [12]. These studies also evidence the lack of tool support of green computing, not only at the code level, but also at higher abstraction levels –i.e., requirements and software architectures levels [2]. The main conclusion of these studies is that software developers need more precise evidence about how to tackle the energy efficiency problem and some tool support that help them to effectively address it [12] [16].

There are plenty of experimental approaches that try to identify what parts of an application influence more in the total energy footprint of an application –i.e., to identify the energy hotspots [14]. An important part of these works proposes to minimize energy consumption by focusing on code level optimizations. They report the energy consumption of different implementations. For example, of data collections in Java [4], or system calls in Android applications [7]. There are however other works that demonstrate that changes in architecture design tend to have a larger impact in energy consumption [3]. However, analysing the expected energy consumption of so many alternative architectural solutions is not a trivial task. Developers would need tool support that helps them to measure, analyse and reason about alternative architectural solutions to energy hotspots —i.e., the set of components that implement a given energy hotspot (hereinafter, energy-consuming concerns).

One of the benefits of addressing the energy efficiency at architectural level is to provide software developers with the necessary means to analyse the energy consumption of different alternative solutions, before implementing them. Energy absolute values are not needed, because what is important for developers is to be able to compare the energy consumed by different architectural alternatives [6]. There is no doubt that the green computing community has made many steps forward in the development of green software architectures. Some relevant examples are the catalogs of energy-aware design patterns [13] and architectural tactics [18], as

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well as new architecture description languages that incorporate an energy profile and analysis support [15, 20].

However, we argue that there is still not enough tool support that helps developers to clearly identify the energy-consuming concerns in their applications, and moreover to choose and generate the most appropriate architectural solutions from an energy consumption point of view. On the one hand, recent studies although complementary, are disconnected, so their results cannot be easily applied to the development of green applications in an integrated way [11]. On the other hand, these studies do not always consider that some energy-consuming concerns (e.g., to store data locally or remotely) have strong dependencies with others (e.g., to store data remotely will depend on the communication concern, and the latter one, on the security concern) [10]. Moreover, usually the results of these studies are not easily accessible for practitioners, which do not know how to apply and reuse this knowledge in their applications [2, 12, 16, 17]. In order to cope with these limitations we consider that software developers need some kind of ‘assistant’ that guides them through all the steps required to identify, model, analyse and reason about different architectural solutions to energy-consuming concerns.

In this paper we present the HADAS green assistant, that aims to help developers to generate the most energy-efficient architectural configurations that fulfil the application requirements. This assistant will suggest a set of energy-consuming concerns (i.e., points in the application that consume more energy, like encrypting or transferring data) and for each of them it will show the list of possible architectural solutions, along with an energy function. Each of the provided solutions were previously modeled and their energy consumption calculated or predicted, before storing them in the repository (for predictions we use Palladio Power Consumption Analyzer [20]). So, HADAS drastically reduces the effort of analysing the energy consumed by different architectural solutions, which in other works has to be performed from the scratch. HADAS internally models the variability of the architectural solutions for the energy consuming concerns using variability models, concretely the Common Variability Language (CVL) [5] (e.g., cache memory can be modeled as a optional feature). It also models the architectural dependencies between different energy-consuming concerns, meaning that the computation of the expected energy consumption of one of those concerns, also considers other concerns needed to apply a specific architectural pattern (this is not always considered in other works).

To sum up, with the HADAS green assistant, the developer can choose among different alternatives for a particular energy-consuming concern (e.g. storing information, communication or compression) and will be able to analyse and reason about the energy impact of each design decision. Finally, this tool will automatically generate the architectural configuration derived from the selections made by the developer from an energy consumption point of view.

After this introduction and the related work described in Section 2, the requirements to implement the HADAS green assistant are detailed in Section 3. Then, in Section 4 the HADAS green repository and the HADAS green assistant are described from two different points of view. One is the use of the green assistant by the software developers of green applications. The other one is the technical details regarding their implementation. Our approach is evaluated and the results discussed in Section 5. Finally, the conclusions and on-going work are described in Section 6.

2. Related Work

In order to better motivate our work, we have reviewed papers focused on: (1) experimental studies at the code level (CL); (2) proposals at requirement (RL), architecture (AL), and design levels (DL); and (3) studies about energy consumption awareness of software developers. Due to the large number of existing works, and the rapid changes in this area, we will narrow our study to those papers published in last editions of relevant (energy-specific) software engineering conferences and journals. We consider these are representative papers of current research in this area.

Table 1 summarizes the different papers we have considered in this section. For each of them we indicate the level at which the paper focuses (second column), the type of paper (third column), whether dependencies are considered or not (fourth column), the main output (fifth column) and the knowledge that is derived from this work (sixth column).

Firstly, in rows 1 to 7 we can observe that a large number of papers present experimental studies performed at the code level. A common goal to all of them is the definition of energy profiles for different energy-consuming concerns. These experimental studies usually focus on one particular energy-consuming concern (e.g. communication or data storage) without considering the dependencies among them. It is important to highlight that a few of these proposals provide some support to integrate/reuse the knowledge obtained from experimental studies. For instance, the work in [19] (row 5) defines a wiki with a template to integrate all the results from different experimental studies and the work in [12] (row 6) defines a framework to integrate different energy-efficient alternatives. But none of them, model explicitly the variability of energy consuming concerns, losing the opportunity to automatically generate and manage green product configurations.

There are also an increasing number of proposals that focus at higher levels of the software development, such as design (row 7) or architecture (rows 8 to 10). Focusing on high level proposals, we can distinguish between experimental works (row 7) and modelling works (rows 8 to 10). Some of these modelling works are architecture description languages that provide support for analyzing energy con-
| Proposal | Level | Type | Dep. | Output | Knowledge |
|----------|-------|------|------|--------|-----------|
| Hasan [4] | CL    | Exp. | No   | Energy profiles of operations on Java Collections. | It claims that a per-method analysis of energy consumption must be made. |
| Li [8]   | CL    | Exp. | No   | Multiple HTTP requests are bundled to reduce energy consumption. | HTTP requests are one of the most energy consuming operations. |
| Chen [1] | CL    | Exp. | No   | Performance and energy consumption profiles for cloud applications. | Tool support is needed; also using realistic application workloads. |
| Li [7]   | CL    | Exp. | No   | Quantitative information about the energy consumption of Android apps (405 apps) | More than 60% of energy consumed in idle states; the network is the most energy consuming component; developers should focus on code optimization. |
| Procaccianti [19] | CL    | Exp. | No   | Report on two green software practices: use of efficient queries and put applications to sleep. | Software design and implementation choices significantly affect energy efficiency. The effectiveness of best practices for reducing energy consumption needs to be precisely quantified. |
| Manotas [11] | CL    | Fram. | No   | Define the SEED framework for the automatic optimization of energy usage of applications by making code level changes. | Support is needed to integrate the insights gained by existing experimental studies to help identifying the more energy-efficient alternatives. |
| Noureddine [13] | DL    | CL   | Exp. | Empirical evaluation of 21 design patterns. Compiler transformations to detect & transform patterns during compilation for better energy efficiency with no impact on coding practices. | The energy consumption of design patterns highly depend on the running environment; several studies identified both patterns and anti-patterns regarding energy consumption. |
| Procaccianti [18] | AL    | Mod. | Yes  | Identify energy efficiency as a quality attribute and define green architectural tactics for cloud applications. Identify relationships between different architectural tactics. | Energy efficiency has to be addressed from a software architecture perspective. Software architects need reusable tactics for considering energy efficiency in their application designs. |
| PCM [20]  | AL    | Mod. | Yes  | Architecture Description Language and tool set with support for the specification, calculation and analysis of energy consumption. | At the architectural level the energy consumption can be estimated based on resource consumption (CPU, HDD, etc.) and usage models. |
| AADL [15] | AL    | Mod. | Yes  | Plug-in integrated with the AADL tool to support the specification and analysis of energy consumption. | It focuses in the energy overhead of inter-process communication, an important service of embedded systems. |
| Pinto [17] | CL    | EmpSt. | -   | Qualitative study exploring the interest and knowledge of software developers about energy consumption | Lack of tools; many misconceptions and panaceas. Major causes for energy consumption problems are identified. |
| Chitchyan [2] | RL    | EmpSt. | -   | Qualitative study exploring requirements engineering practitioners behaviour towards sustainability (including energy consumption). | Lack of methodological support; lack of management support; requirements trade-off and risks, ... |
| Manotas [12] | RL    | AL    | EmpSt. | - | Qualitative study exploring the knowledge of practitioners interested on energy consumption from different perspectives (requirements, design and construction). | Green software practitioners care and think about energy; however, they are not as successful as expected because they lack necessary information and tool support. |
| Pang [16]  | CL    | EmpSt. | -   | Qualitative study exploring the knowledge of practitioners about energy consumption. | Programmers rarely address energy. There are important misconceptions about software energy consumption. |

CL - Code Level, AL - Architecture Level, DL - Design Level, RL - Requirements Level  
Exp. - Experimental Work, Fram. - Framework, Mod. - Modelling Work, EmpSt. - Empirical Study (Questionnaires)
The implementation of a green assistance implies addressing energy consumption of their applications methodologically and tool support and software developers worried (or not) about the energy consumed by their applications) are considerably increasing in last years (see rows 11 to 14). As indicated in the introduction, the results of all these empirical studies are the same: there is a lack of methodological and tool support and software developers have still many misconceptions about how to reduce the energy consumption of their applications.

3. Green Assistant Requirements

The implementation of a green assistance implies addressing the following requirements:

- **R1: Identify and model the energy hotspots.** Since developers do not have yet enough knowledge about what concerns could impact more in the power consumption, the green assistant should support them in this task. Although recent works propose different architectural tactics to implement concrete energy hotspots, none of them explicitly model the architectural variability of the energy consuming concerns. Additionally, the energy consuming concerns associated with every energy hotspot could depend on other energy consuming concerns. But these kinds of dependencies often go unnoticed by the developer, and so they do not include them in the energy analysis. Then, the green assistant should automatically include those energy consuming concerns that depend on the ones already selected by the developer. The variability models and dependencies should also be part of the models stored in the green repository.

- **R2: Design the architecture of every valid configuration and resource consumption of each component.** Up to the moment, if a developer wants to know the resource consumption of a concrete architectural solution that fits an energy hotspot, they need to manually specify the architecture and calculate the resources needed by each component (for example, with Palladio). Considering that for a given energy hotspot there could be many solutions, designers would not be interested in doing this for every alternative. But, without this information it is not possible to guide the developer in selecting the most energy efficient solution. So, the great challenge here is to provide the developer with a pre-defined architecture for each of the variants of every energy consuming concern, and an estimation of the consumed resources. The benefit is twofold: (i) the developer knows in advance the resources needed by the energy consuming concerns of their application, simply clicking a button; (ii) the architectural design of the selected solution can be reused, being part of the final architecture of the application. These models should also be part of the green repository.

- **R3: Calculate the energy function of each architectural configuration.** We have already seen that the energy consumed by an application usually depends on input parameters, but the challenge is who is going to define the energy function for a concrete architectural configuration. The only way of making this is manually, so ideally the green assistant should already provide this information. Since an application usually has to include many energy consuming concerns, having the function of each of them previously calculated will help designers to see the power consumption of the final application, and make some corrections in their decisions if it is necessary. Finally, this information should enrich the models stored in the green repository.

- **R4: Implement the user interface of the green assistant tool.** The approach presented in this paper is not viable without a user interface. This user interface should show: (i) the list of energy consuming concerns associated with the energy hotspots; (ii) the options available and a mechanism to enable and disable other options (i.e., other energy consuming concerns) according to the dependencies identified in R1; (iii) a energy efficiency analysis with graphics showing the energy consumption in function of some input parameters; (iv) an option to generate the architectural configuration corresponding to the selections made by the developer from the energy consumption point of view.

4. The HADAS Green Assistant

In this section we will present the HADAS Green Assistant tool, focusing especially on describing the HADAS Green Repository. They are described both from the point of view of the software developers who want to use it and from a technical perspective. Suppose that Alice is a software developer that wants to develop an energy-efficient application. We will use a Media Store application, previously implemented and defined in Palladio, to illustrate our proposal and the advantages of using our tool for choosing energy efficient architectures adapted to the requirements.

If Alice wants to use the HADAS Green Assistant, she must follow the steps shown in Figure 1. Note that we will describe these steps in italic letter in order to differentiate...
4.1 Energy Consuming Concerns

The first step (Figure 1, label 1) is to identify energy hotspots in the application requirements. Alice is going to develop the Media Store application, so she needs to store audio files in a server and/or to encode these files, among other functionality.

The HADAS Green Assistant has previously identified these kind of concerns as energy consuming. For instance, Store (e.g., upload an audio file) and Compression (e.g., encode an audio file). We have explored nowadays applications in order to identify the main energy hotspots that are repeated among many of these applications. So far our repository have a list of 10 energy consuming concerns, as can be seen in Figures 2 and 3: Store, Communication, Compression, Security, Data Access, Notification, Synchronization, User Interface, Code Migration and Fault Tolerance. Of course, this list will be augmented when we have new evidence about other energy hotspots.

The second step (Figure 1, label 2) for Alice is to select the energy-consuming concerns in the HADAS repository.

4.2 Variability Model and Dependencies

The third step for Alice (Figure 1, label 3) is to choose the options for every energy-consuming concern selected in the second step. The HADAS assistant will show the application developer a separated google form for every selected concern and in our case Alice has to select the alternatives she wants to explore to analyze later the energy efficiency. For instance, the store could be done locally and/or remotely, there are many encryption algorithms, or different codecs to compress audio or video files). Additionally, these concerns are not independent from each other. For instance, there are several concerns related with Communication, such as Data Access, Store, Notification, Synchronization or Code Migration. This means that there are dependencies between them and, therefore, the energy consumption cannot be analyzed isolatedly for every concern. Instead, a whole architecture should be analyzed, where these dependencies are explicitly modeled and taken into account. In the next subsection we will see how this variability and the dependencies are modeled in our approach.
files have to be uploaded to a remote server. The Communication concern, which is the responsible for sending the file, was previously identified by HADAS as another energy consuming concern and it is included in the repository. Thus, communication is required to upload the files and must be included in the analysis in order to know how much energy will be consumed by the whole architecture. However, Alice was not aware of the dependency between the remote storage in a server and communication and, thus, she did not explicitly select the Communication concern during the first step (as can be seen in Figure 2). However, this is not a problem when using HADAS because, in order to make easier the developer job, the HADAS assistant will automatically show the options available for the Communication concern. This is possible because the HADAS repository contains information about the dependencies between different energy concerns.

We have modeled the energy consuming concerns variability and the dependencies between them using the Common Variability Language (CVL). CVL allows modelling the variability separately from a base model (i.e., architectural model), but both the variability and the base models can be connected and can be managed using the same tool. In particular, using the CVL tools we specify the Variability Model (called VSpec tree) and the binding between this and the Base Model. With a VSpec tree we can specify the common features that must be part of the architectural solution for a given energy consuming concern, and also their variants (e.g., to store data locally or remotely).

Some of the features of this variability model can be seen in Figure 3. We have depicted part of the variability for some concerns related to the Media Store case study. The rest were not included for the sake of simplicity and also because it is out of the scope of this paper. Specially, Figure 3 shows part of the variability for the Store concern, the variability of the audio codecs of the Compression concern and also the Encryption variants of the Security concern. We have put in bold the lines of the selected features that correspond to Alice’s checkbox selections in the forms shown in Figure 2. Concretely, Alice has selected to store the files in a Server and to explore four different codecs or algorithms for the audio compression: LAME, Vorbis, jFLAC and JSpeex.

Note that Communication is also selected in the variability model of 3 (marked in a bolder red line). This is because Alice selected the Server feature of the Store concern and there is a cross-tree constraint between this and the Communication concern that implements the dependency between both concerns. This constraint is called Comm in the figure and it is marked in red. It formally defines the mutual dependency as: Server implies Communication.

With CVL it is possible to generate automatically the Resolution Models after selecting (True or False) a set of choices in the variability model. These selections in the variability model are obtained from the selections in the google forms. A Resolution Model represents a set of alternatives for every selected concern that the developer wants to explore during the analysis of the power consumption. Every alternative corresponds with a concrete architecture of the base model. We will detail how we define this architecture in next subsection. The benefit of using the HADAS assistant is that the specifications of the variability model and the generation of the resolution model, as well as the specification of the alternative software architectures, are steps completely transparent to Alice, who only has to deal with the google forms.

4.3 Architecture and Energy Consumption Simulations

Once Alice has selected the energy consuming concerns and the variants for the ones she wants to explore, she has to make an energy-efficiency analysis of the different alterna-
The variability model of the HADAS Green Repository in CVL (Figure 3) as the fourth step. HADAS will help her to be aware of the energy implications of their decisions.

The energy consumption of each concern variant is expressed by means of energy functions parameterized by variable parameters (e.g., the audio file size). HADAS does not pretend to provide the exact consumption in Watts, because what Alice needs to know is which alternatives are more energy consuming than others, and which ones can be considered more green. This is an iterative process, since Alice can select different options for several concerns and analyse the impact of each of her decisions in the energy expenditure of the application. So, the HADAS Green Assistant will show the energy consumption for every concern but also for the whole architecture, since as mentioned before the concerns are not independent from each other. Then, as we describe in the next section, we need to be able to simulate the energy expenditure and of all the possible architectural alternatives of all the concerns. In this way the HADAS Green Assistant will provide the energy functions for every configuration generated from the variability model described in the previous subsection.

The Base Model of CVL must be a MOF compliant model of the software architecture, which in our case is the set of components and connections that specify a concrete concern variant. Since we need to include the expected energy consumption of each variant, we have to use an architectural model or language that provides this kind of information. We have chosen to model the architecture using the Palladio Component Model (PCM) due to the powerful toolset that provides (Palladio) to analyse the resource consumption at architectural level (including the energy). The metamodel of PCM can be implemented in MOF, so it can perfectly be used jointly with CVL. Therefore, in order to automatically provide the energy consumption functions for the configurations we connect the CVL variability model (VSpec Tree) with the respective architectural base model specified in PCM. Figure 4 depicts some of the components that provides the Compression interface to compress audio files of different formats using different algorithms or codecs.

Figure 3. The variability model of the HADAS Green Repository in CVL

Then, using the Palladio Power Consumption Analyzer we simulate the different configurations to obtain the power consumption. Thus, the application developer will automatically know how the energy consumption varies when they select different alternatives for the selected concerns. The total number of alternatives when there are several selected concerns could be really high, so reason about and simulate the energy expenditure of all these possible alternatives by hand for every application is not possible. HADAS helps to that by previously simulating the energy expenditure of every possible configuration of our repository with Palladio. This takes a lot of time, but with our approach it has to be performed only once. The benefit for the developer is that they do not have to make any resource consumption simulation by hand. The tool will show the results so that the developer only has to analyse the different results.
Furthermore, thanks that HADAS takes into account the dependencies between different energy consuming concerns, Alice will be able to make complex decisions with no so much effort. For example, Alice can decide not to include the possibility to upload compressed audio files when they are too small (less than 5 Mb). She was able to make this decision, because the energy consumption functions provided by HADAS take into account both the energy expenditure to compress the file and the energy expenditure to send the compressed file to the server. This has been possible because HADAS exploit the dependencies between the concerns. Then although in the Media Store requirements Alice did not identified communication as a energy hotspot, HADAS automatically suggested her to consider also this concern. It showed the different energy functions for the upload functionality including also the compression (specified as another cross-tree constraint). This is very important since, as will be detailed in next section, the decisions taken could be different if we analyse the audio compression without considering the communication and vice versa.

The last step Alice has to perform (Figure 4 label 5) is to get the architectural configuration from the HADAS repository simply clicking a button. For that, HADAS will generate the architectural configuration including the definitive options Alice has selected after the analysis in the step 4) using our implementation of the CVL engine. For instance, HADAS will include in the configuration (i.e. the resolved model in CVL) components for the Store, Compression, Data Access, Security and Communication concerns corresponding to the options chosen by her. In this case Alice, will have to complete the application with the rest of functionality considered not relevant for energy efficiency (e.g., audio file edition).

5. Evaluation

In this section we are going to detail how we perform the simulations that are needed to be able to inform, through the HADAS green assistant, about the power consumption of the alternative architectures software developers want to explore. We perform the simulation in advance to store in the HADAS green repository an energy function that will provide how many watts every one of the possible configuration of each concern are going to waste, at least in relative terms – i.e., which one of the different variants waste less and which one more. We differentiate two main steps. A first step where we perform the experiments to obtain the energy functions for each energy-consuming concern. And a second step where we integrate the information from the experiments into the Palladio Consumption Analyzer in order to simulate the joint use of several dependent concerns.

5.1 Experimental studies

For every energy-consuming concern we have carried out a set of experiments measuring the energy waste with Joule-meter a Microsoft modeling tool to measure the energy usage of software applications running on a computer. This tool has been calibrated using Watts'Up to obtain the real power consumption of every hardware component (e.g., CPU, HDD, Screen, ..). All the experiment has been conducted in a Gateway DT30 Desktop PC with Intel Core 2 Quad Q9300, 2.50GHz and 8GB of RAM under Windows 10, 64 bits. And all the concerns have been implemented in Java.

Remember that Alice chose 4 different audio codecs to compress audio files because she wanted to know which one(s) were more appropriate, from a energy point of view, to be included in her Media Store application. So, in order to let her know which one is more energy efficient for her application, in the step 4 described in previous section, the HADAS green assistant could show the graphic of Figure 5.

This graphic shows the power consumption (in a logarithmic scale) to compress 9 WAV audio files of different sizes (from 5Mb to almost 1GB) using the following audio compression algorithms: Java LAME 3.99.3 to create MP3 audio files using a bitrate of 128Mb, Vorbis-java (libvorbis-1.1.2) to compress in OGG files, javaFlacEncoder 0.3.1 for the FLAC algorithm and Java Speex Encoder v0.9.7 indicated as SPX in the figure. Then, Alice could explore which one is more energy efficient for her application. For instance, if it is a media store for managing music songs, the typical file sizes could be between 15-35Mb, so she only would need to look at this information. As can be observed in the graphic for these sizes, the most energy efficient algorithm is LAME to compress in MP3 files since it consumes less than 0.3 Watts, meanwhile the other three consume more than 0.6, the double.

However, the analysis of this information in an isolated way is not enough to let Alice takes a decision of which algorithm to use for her application since the compression concern will not be used alone. Typically, the Media Store

1. https://www.microsoft.com/en-us/research/project/joulemeter-computational-energy-measurement-and-optimization/
2. https://www.wattsupmeters.com/secure/products.php?pn=0
will compress the audio files before uploading them to the server. Then, in order for Alice to reason in a proper way, she needs to know the total power consumption to both compress the file and to send it to the server. Notice that the different compression algorithms produce compressed file of different sizes, and therefore the energy consumption for the communication concern will be different depending on the compression algorithm previously used. Then, in order to simulate the energy consumption of both concerns working together we use the Palladio Power Consumption Analyzer.

5.2 Simulation with the Palladio Analyzer

As previously described, we have in the HADAS repository the architectural components modelling the energy consuming concerns with all their respective alternatives, and with information about how they are connected between them. These models are defined in the Palladio PCM repository diagram. Then, for every component we have also defined its behavior in a Service Effect Specifications (SEFF) PCM diagram. In these diagrams we have also included the energy models that represent the power consumption of the internal actions (or methods) of the behavior, which have been previously calculated taking the measures from the experiments with Joulmeter, as explained for the compression algorithms.

Then, using the Palladio Power Consumption Analyzer we can simulate how much energy the two concerns working together consume, as shown in Figure 6. Note that this is not as simple as sum up the Watts of the two actions (compression and communication) since the communication energy waste depends on the size of the file to be sent and this size strongly depends on the compression algorithm used. In this graphic, we have also included the power consumption of sending a WAV file without compression. We can observe that for not too big files (less than 20Mb) it could be more energy efficient to send the file without being compressed than to compress it using either the JavaFlacEncoder 0.3.1 for the FLAC algorithm or the Java Speex Encoder. Then in this case, for the typical file size of WAV song files the decision is not so clear as before. For instance, for 30Mb files the energy consumption of first using LAME, Vorbis and Speex to compress the file and then upload the compressed file to the server is very similar, so Alice could chose the one that fits better with other requirements as, for instance, the audio quality. However, she could avoid the FLAC algorithm for her media store application. But, if the media store was dedicated to manage short audio recorded messages with size of less than 10Mb this algorithm is the more energy-efficient to compress and to send the file to the server. However, the FLAC algorithm is the one that more power consumes for big files. Then, for a media store to manage long audio conferences it would consume much less the Speex algorithm. These differences of energy consumption were not so high when we simulated the compression algorithms alone.

Therefore, thanks to our proposal, where we use also Palladio to make the previous simulations, Alice is able to explore all the alternatives for all the energy-consuming concerns available in our repository. Of course, our assistant will show her all the alternatives for the five concerns she selected, not only for these two. So she will be able to analyze the simulations and pick the more proper and energy-efficient alternatives for the whole architecture.

5.3 Discussion

Performing the experiments for all the individual concern and the later simulations using Palladio for all the possible configuration of the concerns are time-consuming and not easy tasks. However, these tasks have to be done just once when adding the concern to the repository. Then, this information can be (re)-used for many different applications, having many advantages for the application developers:

1. It helps them to identify potential energy hotspots in their application, just looking into the requirements and in the HADAS assistant form. Then, they could be aware of them when implementing the application.

2. It detects the dependencies between the concerns automatically, helping the developers to take into account other hotspots that previously were not identified, as happened before to Alice with the Communication concern.

3. It allows them to explore a high number of alternatives at a glance, just making a few clicks in the form. In [20], in order to justify the functioning of the Palladio Power Consumption Analyzer, the authors change the LAME algorithm for the Vorbis algorithm in their media store. But this is done manually and the simulation of the whole architecture has to be performed as a consequence of changing only one component for another. With our assistant Alice has to perform just 4 clicks to be able to explore the 4 algorithms (2 algorithms more than in [20]) and to decide which one to use for her application. Then, the HADAS assistant provides her the PCM system diagram with the concrete alternatives she has chosen. Without our assistant instead of making 4 clicks, she...
would have to test manually how many energy the different compression algorithms waste, and then to modify the original media store architecture by hand to simulate the 4 different whole architectures. Moreover, if she wants to explore the variability in other concerns the number of possible architectures grows exponentially, which it would be very difficult to manage.

4. Our results are accurate to decide which architectures are more energy efficient than others. In [20] authors demonstrate that Palladio Power Consumption Analyzer is suited to accurately predict energy consumption on an architectural level. Therefore, as we are using this tool to make our simulations we can conclude that the results we offer are also accurate. Anyway, as we have explained several times, our purpose is not to predict the exact number of watts wasted for a variant, but which one could be more energy-efficient than other.

6. Conclusions

In this work we have presented the HADAS Green Assistant, a tool that helps application developers to be energy-aware when they are designing their applications trying to produce energy-efficient software. In order to develop the green assistant we have built a green repository composed by energy consuming concerns. These concerns represent the different ways of implementing the energy hotspots we have detected in nowadays applications, as data storage and access, communication, compression and so on.

We have modeled the concerns using variability models to manage the different implementations. The variability models represent both all the possible alternatives for each concern and the dependencies between them. It is really necessary to take into account these dependencies because we want to offer to the application developers the possibility to reason about energy consumption of the whole software architecture, and the concerns are working together for one application, not in an isolated way. Therefore, to provide the power consumption of every concern throw experimental tests it is not enough. We have conducted also simulations in Palladio to store in the HADAS repository the energy functions associated to any possible configuration of all the concerns working together.

The HADAS green assistant offers also a very intuitive graphical user interface based in forms that the application developers have to fill in order to select which energy consuming concerns they want to consider and which alternatives they want to explore.

About future works, we plan to exploit the variability models representing the energy consuming concerns to used them also at runtime. It is well known that the real energy consumption of an application strongly depends on the data used and on the final usage of such application. Then, maybe the decisions taken at design time are not enough to build real energy-efficient applications. So, we propose to use variability models at runtime to be able to reconfigure dynamically the applications to adequate their concerns to new situations.

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