

Mobile Prefetching and Web Prefetching: A Systematic Literature Review

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Abstract. Today, we see that prefetching systems are widely used to decrease the network traffic, data access latency, energy consumption, and computing performance inefficiency of data-intensive operations. However, prefetching is a concept used in different computing and IT fields such as microprocessor design, micro-controller design, hard disk design, database, network, web application, mobile application, etc. The fact that the concept of prefetching is used in different fields causes difficulties in literature review and research. Therefore, these studies need to be organized systematically for each field. This study presents a systematic literature review of prefetching related mobile and web applications to identify research gaps, define new study subject opportunities, and present future directions. We think that this study will make it easier for other researchers to work in this field with the research gaps and opportunities indicated.

Keywords: Web prefetching · Mobile prefetching · Systematic literature review · Intelligent techniques · Prefetching strategies

1 Introduction

With the development of technology, the internet has an important place in people's lives, easier to access. Companies have started to serve many users and their demands in this way. However, the users are impatient to access the services. The increased demands require improved service [20,37]. Google reported that when searches were answered 100 to 400 ms. late, the number of daily searches per user decreased by 0.2% to 0.6 % [7]. Similarly, it has been shown in various studies that delay problems are directly effective in user satisfaction and revenue growth [5,27].

Bandwidth limitations, distributed design, long query processing, etc., increase the access latency. Better hardware and technologies or intelligent techniques such as caching and prefetching can be implemented to satisfy users suffering from it [29,36,37].

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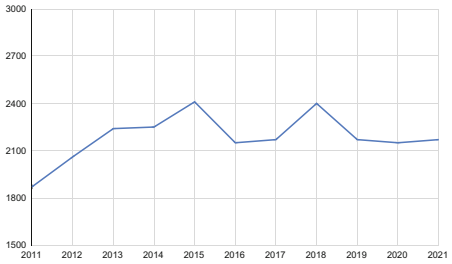

Fig. 1. Search results of "web or mobile prefetching" words on Google Scholar by years

The previously accessed data may be required near future. Because of that, it is stored for reuse in memory [11]. This approach called caching meets client needs in an instant while reducing server-side stress [17,35]. The basic approach to caching includes responding from data stores for the user's request for the first time and storing it in the cache to not occupy the server if the same request is made again. For example, thanks to Facebook's photo caching mechanism, 90.1% of the incoming requests come through the cache, while the rest is taken from the storage space [15].

User's requests in the near future can be predicted from previously accessed data, and responses to the requests can be fetched into the cache [11,29,30, 40]. This approach is called prefetching, another research area to reduce access latency. It aims to minimize user access latency using optimum memory and bandwidth [26,29].

Web prefetching and mobile prefetching is hot topic that has been studying over and over again with novel prediction approaches for near future since past. Search results of "web or mobile prefetching" words on Google Scholar by years support it. This results is shown in Fig. 1 in order to present publication counts year by year. When we scan the literature, we found a systematic literature review for web caching strategies including proxy-side and client-side prefetching [41]. There has not been a systematic literature review or mapping study on mobile and web prefetching that would identify publication trends, research gaps, and future directions.

In this paper, we share our systematic literature review steps and findings on mobile prefetching and web prefetching to identify research gaps, define new study subject opportunities, and present future directions. We share carefully selected publications on prefetching published in the last ten years and some statistics and information we have obtained from these publications. We think that this study will make it easier for other researchers to work in this field with the research gaps and opportunities indicated.

The rest of the paper is organized as follows: Sect. 2 provides information about our systematic literature review process. We answer the research question and discuss outputs obtained from the data extraction process in Sect. 3. The

threats to the validity of the systematic literature review study are presented in Sect. 4, and in the last section, Sect. 5, we describe a conclusion and future work.

2 Systematic Literature Review Process

SLR or SMS aims to review all the primary studies to identify, classify and compare the research area and answer the research questions. SLR provides a clear perspective to literature for future direction through methodological steps. We follow the methodology presented by Petersen et al. [34], which includes planning, conducting, and documenting. We have applied systematic literature review method to our secondary study research on topic of "Web or Mobile Prefetching: A Systematic Literature Review".

2.1 Planing the Review

We define the research questions to obtain literature knowledge and to give a form to the review process. In the Table 1, research questions and main motivations of them are displayed.

Table 1. Research questions

Research questions	Main motivation
RQ1: What are the main practical motivations behind using prefetch?	The aim is to get ideas about the main reason for organizing the software architectures with prefetching modules
RQ2: How many studies are published on the web or mobile prefetching?	The aim is to provide a trend analysis graph
RQ3: What are the most frequently used prediction methods for prefetching?	The aim is to provide information on the most frequently used techniques
RQ4: What are the existing research issues, and what should be the future research agenda?	The aim is to understand and reveal the research gaps and identify future research directions
RQ5: Which journals include studies on the web or mobile prefetching?	Identify the journals for authors to submit their studies

2.2 Search String to Find Primary Studies

In order to find primary studies, we have defined a search string including mobile, web, and prefetching keywords. The search string we have defined is "(Mobile OR Web) **AND** Prefetching."

Using the search string, we collect results from 4 digital libraries between 2011 and march 2022. The name of libraries and how many papers are downloaded from the library are presented in Table 2. It isn't easy to download, organize, and manage the papers manually. Therefore, Zotero [3] references management tool was used. The search results were automatically imported to Zotero, the papers were organized, duplicated papers were removed, and filters and exclusion criteria were applied.

Table 2. Search results in digital libraries

No	Name	Result
1	IEEE	378
2	Science Direct	703
3	ACM	1606
4	Springer Link	1402
	Total	**4089**

Table 3. Applied filters to search results

Filter	Description
Filter-1	We excluded publications in unrelated journals and conferences and remove duplicate studies
Filter-2	We read the title and abstract of studies and eliminated irrelevants
Filter-3	We read the abstract deeply to apply the our criteria deciding inclusion or exclusion of studies

We applied three filters described in Table 3 to find out the primary studies. The number of obtained papers after the filters are shown in Fig. 2. The Filter-1 described in Table 3 is applied to search results obtained from 4 digital libraries IEEE, Science Direct, ACM, and Springer Link. At the last moment of the filtering process, we get 102 primary studies.



Fig. 2. This figure shows the number of studies left after applying the filters defined in Table 3.

2.3 Inclusion and Exclusion Criteria

In this systematic literature review study, we collect search results and eliminate the results according to our first two filter descriptions shown in Table 2. However, we need to select the appropriate papers objectively and answer the research question with the selected papers. For this reason, we determined inclusion and exclusion criteria, presented in Table 4, at the beginning of our study [22,31,34].

Inclusion Criteria. From the remaining paper after Filter-1 and Filter-2, We included studies whose abstract or keywords contain "prefetch" term. We also include studies that contribute to mobile prefetching and web prefetching, such as a theory, a demonstration, an approach, etc.

Exclusion Criteria. We excluded studies that do not openly associate with SLR topics. We did our searches from digital libraries, but we decided from the beginning to exclude possible blog and presentation files that we might encounter. The prefetching studies on the CPU, memory, microprocessor, flash storage devices and networks are excluded because of domain differences and SLR limitations.

Table 4. Inclusion and exclusion criteria

In/Excl	Criteria
Inclusion	Abstract/keywords include the term "prefetch"
	It is clear from abstract that it is contributes to mobile or web prefetching
Exclusion	Blogs and presentations are excluded
	Hardware-based prefetching studies, for example, prefetching studies on CPU, memory, microprocessor, flash storage devices, etc., are excluded
	The prefetching studies on networks are excluded

2.4 Classification Schema

We categorized 102 studies left after the filtering process according to places of prefetching [4,8] and prediction methods [29,41]. We created a column for each study called "objective," including the study's objective, and tried to extract some things from research fields. We also labeled the research issues and obtained a data extraction form based on this. Eventually, we classified 102 studies according to classification schema presented Table 6.

Table 5. Classification schema

Category	Subcategory	Definition
Prefetching places	Server-side	Even at the origin server, the data can be stored in a server-side for reducing the need for redundant computations or database retrievals [4]
	Client-side	It is located in the client machine [8]
	Proxy-side	It is located between client machines and origin server [4]
Prediction method for prefetching		The future access data can be predicted by a method such as lstm, k-mean, c-mean, etc., for prefetching. This the category defines the prediction method to help the prefetching decision [41]
Research issues	Long resource loading time	One of the aims of prefetching is the reducing latency and satisfying the impatient users [10,23,24,28,41]
	Energy consumption	The prefetching system, especially on mobile and IoT devices must concern with energy consumption [14,23,29]
	Computation intensive operation	The prefetching cache mechanism can improve all system performance. Computational intensive operations demanded in the near future can be calculated by a prefetching mechanism in advance [23,24,28,41]
	Network traffic	The prefetching system, especially on mobile and IoT devices, must also be concerned with network traffic issues to overcome data transfer, energy consumption, connections cost, etc. [4,9,13,33]
	Security and privacy	In the prefetching mechanism, it is necessary to use personal data securely and to protect its privacy [38,39]

2.5 Data Extraction and Mapping of the Literature

To analyze in a planned way, we extracted data from selected primary research studies. We prepared a form to extract data shown in Table 6 and used it to extract data. Research issues, prefetching places, and prediction methods fields were not filled during data extraction unless clearly defined to avoid assumptions.

At the beginning of the data extraction process for 102 studies, we selected a few studies randomly. Then, authors extracted data from the same studies set according to Table 6. We did cross-check, but we couldn't detect any conflict. After realizing that everything was fine, we started to data extraction process for 102 studies to obtain results.

Table 6. Form for data extraction

No	Data extraction column
1	Study ID (ex: S2)
2	Title: Paper's title (ex: Big data stream analysis: a systematic literature review)
3	Author: Author's name
4	Year: Publication year (ex: 2020)
5	Item Type: (ex: Book Chapter)
6	Book Title/Conference Name/Journal Name: Any book, conference or journal name
7	Objective: The propose of the study (ex: Predicting data to be accessed in the near future with association rule mining to prefetch)
8	Prediction Method: Used prediction method in the study (ex: k-means)
9	Research Issue: computation intensive operation, network traffic, latency, energy consumption, privacy or/and security
10	Dataset: Used dataset/datasets to evaluate study (ex: National Lab of Applied Network Research logs)
11	Prefetching Places: client-side, server-side, proxy-side

3 Results

In this section, we discuss outputs obtained from the data extraction process described in the previous section. Each research question presented in Table 1 is answered objectively and evaluated separately using the information in Table 5 and data extracted according to Table 6.

3.1 RQ1: What are the Main Practical Motivations Behind Using Prefetch?

The main motivation of prefetching is to satisfy users and service providers [4, 9,11,29]. In order to better define the motivations, it is necessary to look at the needs from the perspective of the user, provider, and system. The users surfing on the applications can be impatient. Therefore, the motivation is to satisfy the users by reducing latency [2,11,12]. Energy consumption and network usage are essential metrics for the things running on the edge. From this perspective, the motivation for prefetching is reducing consumption [21,25] and network usage [18,33]. The motivation for prefetching of the system provider can be increasing performance, optimizing system resources, and spreading the load to time [1,6,19]. We explained the motivation from different sides for better understanding. However, all these pointed out are the reasons behind using prefetch.

3.2 RQ2: How Many Studies are Published on the Web or Mobile Prefetching?

Within the scope of the study, the studies in the literature in the last ten years on mobile and web prefetching topics were filtered, and 102 primary studies were obtained. The frequency of primary studies by year is shown in Fig. 3. According to Fig. 3, the number of publications has decreased in the last five years. This result seems to be incompatible with search results of "web or mobile prefetching" words on Google Scholar by year shown in Fig. 1.

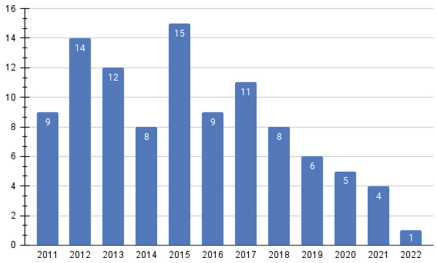

Fig. 3. Selected primary studies frequencies per year

3.3 RQ3: What are the Most Frequently Used Prediction Methods for Prefetching?

Mobile or web prefetching is the approach to predict accessed data in the near future [26,38,39]. We tried to extract prediction approaches for prefetching from obtained primary studies to answer this research question. We read studies profoundly and found out prediction approaches in the prefetching module. However, we realized that while some of the studies to be shared the algorithm's name, the concept and technique were shared in others. Therefore, we extracted terms associated with the predictions for prefetching used in the studies, wrote them down, and calculated frequencies for each term. The key terms are presented in Table 7. According to Table 7, we can group prediction approaches for prefetching as clustering-based, association rule-based, statistical-based, classification-based, and custom approaches.

The prefetching can be implemented in client-side, proxy-side and server-side [16,28,32]. While we were extracting the key terms, we tried to find the proposed prefetching place. In the studies, when we couldn't find that the prefetching place was written explicitly, we tried to understand the prefetching place

from the proposed architecture. We left this field blank when we could not find it in the text and from the architecture. Also, we found in some studies that prefetching can be in more than one place. After reading all the primary studies, the frequency information we obtained about the prefetching place is shared in Fig. 4.

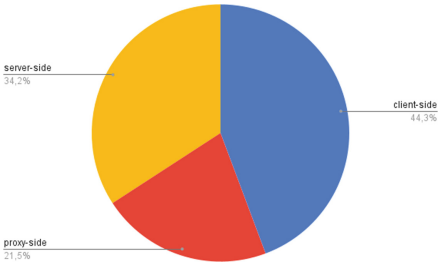

Fig. 4. Prefetching places of some primary studies

3.4 RQ4: What are the Existing Research Issues and What Should be the Future Research Agenda?

In Subsect. 3.1, we have described research motivation on prefetching from different perspectives. We have also described key terms associated with prediction approaches for prefetching in Subsect. 3.3. The answer to these questions gives an opinion about the existing research issues and solution approaches. However, we classified the research issues on prefetching as follows: computation intensive operation [10,23,24], network traffic [9,13,33], long resource loading time [10,23,24,38], energy consumption [23,29], security and privacy [38].

Figure 5 has been created according to the research issues used in our 102 primary studies. Some studies contain more than one research issue. Network traffic, long resource loading time, and energy consumption issues are hot and innovative. With the new prediction methods, novel prefetching approaches can be implemented. According to Fig. 5, prefetching for computation-intensive operation and security and privacy for prefetching are less studied issues, so these may present opportunities for identifying future research directions.

The need for prefetching on edge servers or on the client-side is increasing, especially on mobile phones and IoT devices. Even if prefetching is used, its efficiency needs to be increased. Also, there are things to be done to protect privacy and security while prefetching. Prediction for prefetching without any private data on the proxy-side and server-side are issues that need to be studied.

Table 7. Key terms associated with prediction methods for prefetching extracted from primary studies and their frequencies

Prediction method	cnt	Prediction method	cnt	Prediction method	cnt
amp	1	intentionally-related long short term model	1	prefetch state of bookmarked segments	1
appriori	1	jaccard similarity coefficients	1	prefixspan(pattern-growth dfs)	1
art1 neural network	3	joint probability density function	1	probability graph	1
association rule mining	3	k-means	3		1
bayesian network	3	k-nearest neighbor	2	quickmine	1
bi-lstm	1	k-order markov model	1	rank-based selection	2
breadth-first search latest potentialy pages for users	1	linear svm	1	rate adaption algorithm	1
c-miner	1	Long-time-to-live data types are prefetched	1	referrer graph	1
clasp (closed)	1	lstm	1	rough-set clustering	1
cluster-based	1	lstm-attention	1	semantic-based prediction	1
cluster-based latent bias model	1	markov chain	6	sequential pattern mining	1
compare-by-hash	1	markov decision process	1	skslru	1
competitive agglomeration	1	markov random fields	1	slob	1
context-aware prefetching	1	maxsp	1	social-aware prefetching	1
crowdsourcing	1	mithril	1	socially-driven learning based prefetching	1
dead-reckoning based prediction	1	most popular prefetching	2	spade	1
decision-tree induction	1	most promising pages	1	spam (apriori all bfsdfs)	1
deepevent	1	multi-class svm	1	statistical methods	1
dependency graph	3	navigation trajectory extrapolation	1	stochastic gradient boosting	1
directed graph	1	neural networks	2	stochastic gradient descent	1
directhit	1	newman clustering	1	stochastic optimization	1
double dependency graph	1	omnibox prediction	1	stochastic sequential model	1
epf-dash	1	on/off strategy	2	support vector machine	2
eschedule	1	pagerank	1	tag-based prediction	1
fp-growth	1	palpatine	1	task-level prediction	1
frequently-based prediction	1	partial maching	2	top-n prediction	2
fuzzy c-means	1	path-based next n-trace	1	transparent informed prefetching	1
gradient boosted regression tree	1	pattern-based prediction	1	user access pattern-based prediction	1
greentube	1	petri nets	1	user-aware dynamic markov chain	1
gsp	1	plwap	1	vgen (generator)	1
history-based prediction	3	popularity-based prediction	8	video content analysis	1
hits-based algorithm	2	partial match prediction	2	video slicing mechanism	1
hits-based algorithm	1	history based prediction	1	vmsp (maximal)	1
improved support vector machine	1	preference-based popularity prediction	2	weighted rule mining concept	1

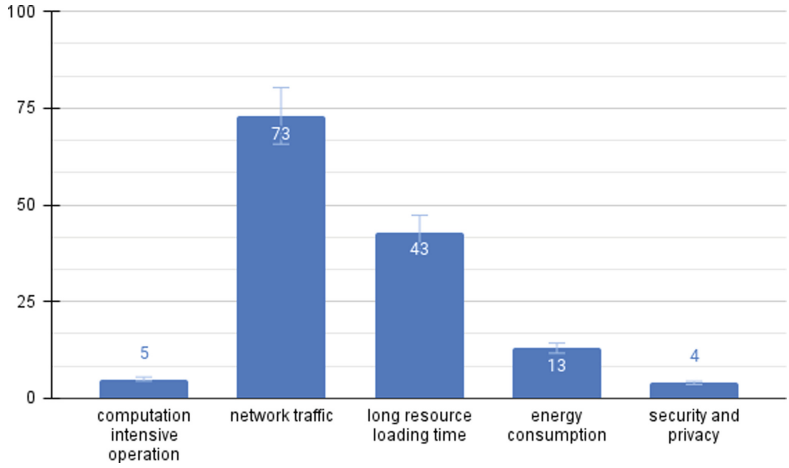

Fig. 5. Research issues on prefetching

3.5 RQ5: Which Journals Include Studies on the Web or Mobile Prefetching?

The journals which accept papers on mobile or web prefetching topics are listed in Table 8 with their scimago journal ranks.

4 Threats to Validity of Research

We discuss the thread of the validity for the mapping study steps to wrong decision makings to identify primary studies, research questions, publication selection, and data extraction.

Publication Selection: Determining the scope of the study was a challenge because prefetching is a concept used in different computing and IT fields such as microprocessor design, micro-controller design, hard disk design, database, network, web, etc. These fields use the prefetching concept in different ways and for different goals. To avoid bias, we searched prefetching terms with mobile and web words separately on digital libraries and collected results with snowballing. But, we can not guarantee that we have accessed all related studies to apply our criteria.

Research Questions: This study is a systematic literature review that logically covers the mobile or web prefetching literature with research questions. But, it may not cover in detail.

Table 8. Journal names

No	Journal name	SJR
1	IEEE Wireless Communications	3,216
2	IEEE Transactions on Wireless Communications	2,010
3	IEEE Transactions on Wireless Communications	2,010
4	IEEE Transactions on Mobile Computing	1,276
5	Future Generation Computer Systems	1,262
6	IEEE Transactions on Multimedia	1,218
7	Journal of Network and Computer Applications	1,145
8	World Wide Web	1,033
9	IEEE Communications Letters	0,929
10	IEEE Systems Journal	0,864
11	Journal of Systems and Software	0,642
12	IEEE Access	0,587
13	ACM Trans. Multimed. Comput. Commun. Appl.	0,558
14	Journal of Intelligent Information Systems	0,424
15	ACM SIGPLAN Notices	0,310
16	ACM Transactions on Storage	0,309
17	ACM SIGARCH Computer Architecture News	–

Data Extraction: The data extraction was done manually by the authors. Therefore, it may contain incorrect decisions. However, we cross-checked during the extraction process, talked together about the conflicts, and decided together.

5 Conclusion and Future Work

In this study, we aimed to investigate literature on the web or mobile prefetching topics systematically and define research gaps and future directions. The main contribution is to present the state of the literature on mobile or web prefetching. By analyzing the trends on this studies topic shown in Fig. 1, an almost equal number of studies are added to the literature each year. According to obtained key terms presented in Table 7, prediction approaches for the prefetching have been grouped as clustering-based, association rule-based, statistical-based, classification-based, and custom approaches. These key terms and groups help to find new research areas. We also defined future directions and research issues in Subsect. 3.3. Based on all this, we conclude that the mobile or web prefetching topic is open to new contributions. Significantly, research on security and privacy for prefetching and prefetching for computation-intensive operations may give good opportunities because of the lack of studies. We will focus on prefetching for computation-intensive operations and security and privacy problems for prefetching in future work.

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