Kernel Implementations of Locality-Aware Dispatching Techniques for Web Server Clusters

Michele Di Santo, Nadia Ranaldo, **Eugenio Zimeo**
RCOST- University of Sannio, 82100 Benevento, Italy
zimeo@unisannio.it

IEEE Cluster Computing 03
Hong Kong
2 December 2003

Introduction 1/2

- The growth of the Web has driven a high demand for powerful web servers
  - End-users should perceive that they are using very responsive services
  - Unfortunately, this goal cannot be easily achieved when a large amount of requests are directed to few popular Web providers
- Solutions that can interest providers should be based on low-cost equipment
  - No changes to the network architecture of the Internet and to Web applications

Introduction 2/2

- Many proposed solutions aim at ensuring scalability and availability by using clusters of computers
  - These clusters are viewed as unique virtual Web servers at the client-side
- Scalability is achieved by distributing the load among the computers of the clusters
- However, selecting a server in a cluster only on the basis of its load condition can be unsatisfactory
  - Modern c/s applications often require secure and stateful transactions
  - These transactions cannot be guaranteed if a content-blind dispatching scheme is adopted
- An increasingly popular technique for selecting a server of a cluster is based on the **request content**

Content-aware dispatching: benefits

- This technique allows each HTTP request to be dispatched toward the “right” real server
- The meaning of the term “right” depends on the objectives that are to be achieved:
  - to support data integrity when SSL is used;
  - to guarantee stateful transactions, as the ones carried out in e-commerce environments;
  - to increase performance, by improving hit/miss ratios in the disk cache of real servers;
  - to achieve a high scalability of secondary storage by partitioning Web documents among different real servers of the cluster;
  - to use heterogeneous and specialized hardware for handling different HTTP requests, such as CGI execution, image retrieval, and so on.

Content at a glance

- We are principally interested in obtaining a small response time by increasing the hit/miss ratio in the disk cache of real servers
  - the other objectives will be pursued in the future work
- Content table:
  - An overview of forwarding mechanisms
  - Description of TCP modifications to support content-aware scheduling at kernel level
  - Some implementation issues of a content-aware scheduling algorithm atop of the modified TCP
  - Performance evaluations
  - A hybrid locality-aware algorithm based on cache prediction
  - Conclusions

Content-aware dispatching: solutions

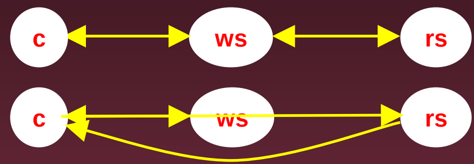
- Content-aware scheduling algorithms need new techniques to enable the dispatching of HTTP requests
- A simple approach consists of using a HTTP server as a dispatcher of requests
  - all the requests are analyzed and managed in the user space
  - a request message must cross all the OS layers to reach the user space, and then go down again toward the network
- A more efficient solution requires that scheduling is implemented at the kernel level of the web switch OS
  - dispatching of TCP segments is easy for content-blind scheduling algorithms;
  - content-aware dispatching is made difficult by:
    - the connection oriented nature of TCP
    - the “three-way handshake”

Dispatching at kernel level

- With the content-aware dispatching, the real server can be selected only after the three-way handshake has been completed
  - A client sends the first part of a HTTP request only after having received the ACK for its SYN segment
- To solve the problem, two solutions can be adopted:
  - avoiding the three-way-handshake;
  - delaying scheduling in order to wait for the arrival of the TCP segment containing the HTTP request
- The former approach could be implemented by using T/TCP
  - it needs changes, both to clients and servers, that have a strong impact on the World-Wide Web infrastructure
- The latter approach requires changes to the OS of the web switch in order to delay the forwarding of packets toward the servers until a HTTP request arrives

Delaying the forwarding of packets

- Two are the most used solutions:
  - TCP-splicing
  - TCP-handoff

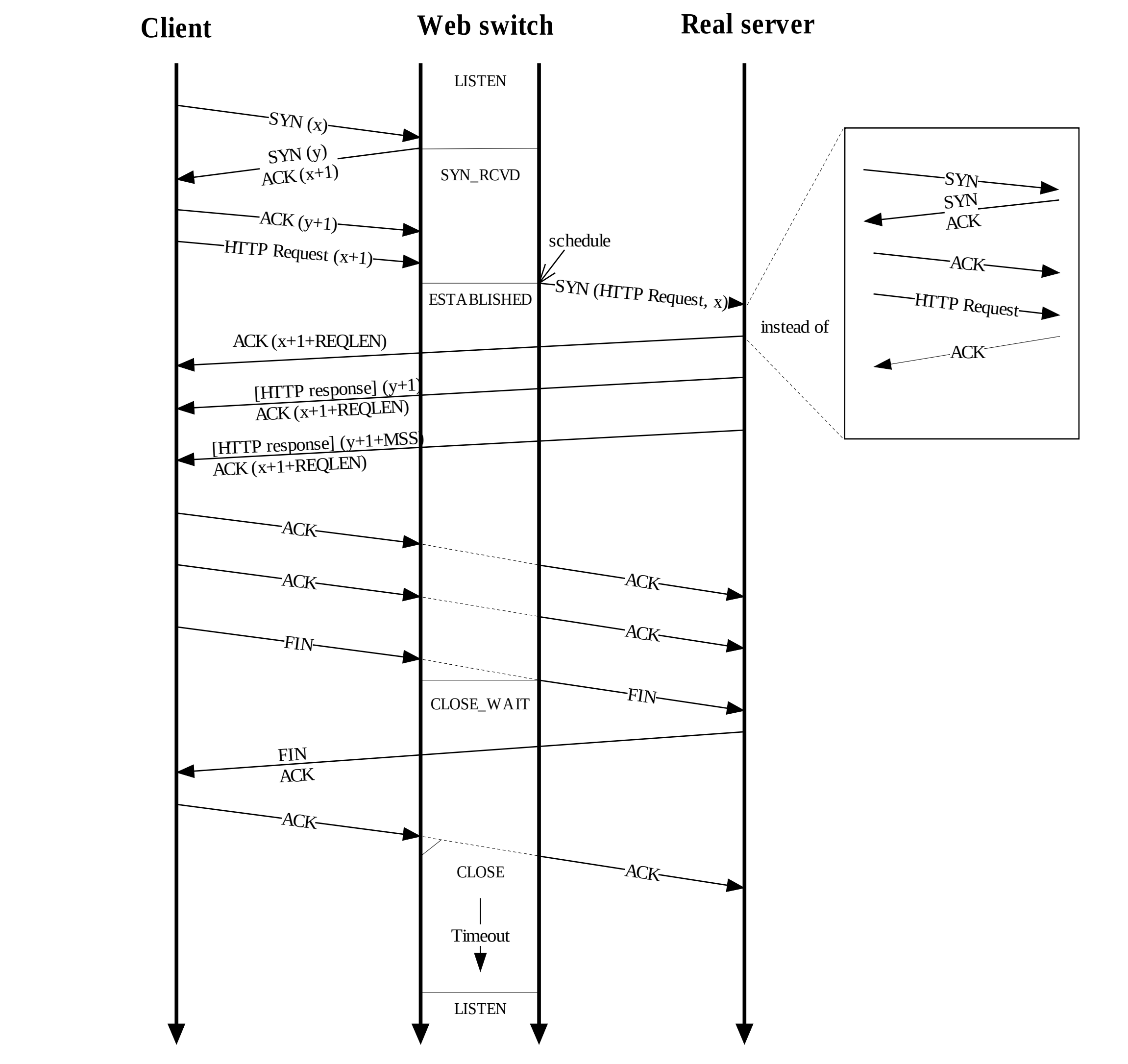


- *TCP-splicing*: two connections are established
  - One between the client and the web switch and another between the web switch and a real server
  - The connection can be spliced by using the NAT
- *TCP-handoff*: one connection is established
  - The web switch establishes a connection with the client and then transfers its TCP state to the selected real server in the cluster

TCP-handoff: our solution $^{1/2}$

- The key idea consists in forcing the selected real server to adopt the *Initial Sequence Number* (ISN) chosen by the web switch during the three-way-handshake with the client
- This way, the real server can directly reply TCP segments to the client
  - Reply segments have to not cross the dispatcher
  - Sequence Numbers (SNs) are not to be rewritten
- Segment routing is based on the direct forwarding of packets from the web switch to real servers
  - MAC addresses re-writing or encapsulation
- However, this approach requires the OS kernel of computers hosting real servers to be modified
  - To make our approach portable, we have introduced a new option at TCP level, called *fast connection option*

TCP-handoff: our solution$^{2/2}$



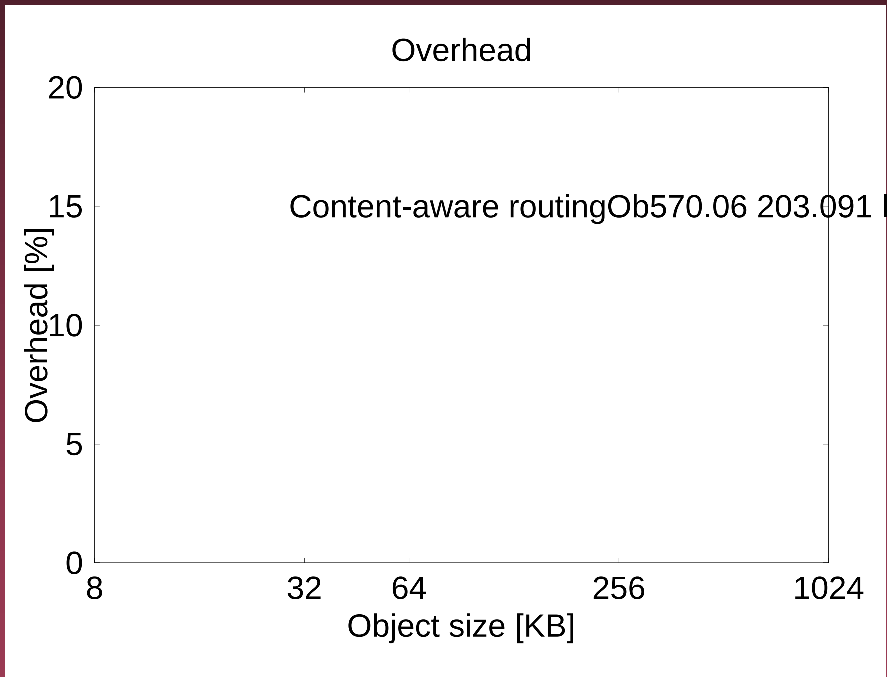
Linux implementation issues

- Our implementation is based on the Linux Virtual Server (LVS)
- LVS uses the IP masquerade mechanism in the kernel 2.2.x and the netfilter framework in the kernel 2.4.x
- Currently we have modified the IP masquerade mechanism
  - A TCP hand-off implementation based on netfilter for the kernel 2.4.x is under development
- LVS provides some forwarding techniques
  - NAT, tunneling and direct routing
- … and supports several

Implementation of a scheduling algorithm

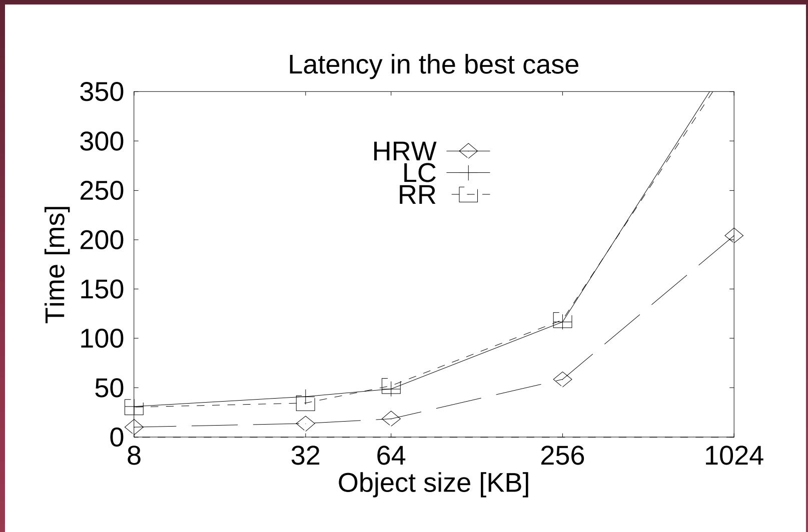
- The mechanism proposed in the previous section has been tested by implementing the *Highest Random Weight* scheduling algorithm
- The algorithm tries to achieve two main objectives:
  - minimizing the scheduling overhead
  - minimizing the latency perceived by users
- HRW is based on a hashing technique that can select a real server by using a hash value associated to the URL (n) contained in a HTTP request:
    - $F(n) = Si : W(n, Si) \geq W(n, Sj) \quad i, j=1,2,\ldots, m \quad \text{and } i \neq j$
- Due to the hash-based mapping, HRW can always associate the same real server to a *n*
  - Increases the hit/miss ratio in the real server disk cache
- The HRW mapping is not static; it is able to select a different real server if the one previously bound to a request has crashed

Content-aware routing overhead



- A reference measurement of latency was obtained by using a direct connection between the client and the server
- Other measurements of latency have been obtained by using the web switch both for content-aware and content-blind routing
- Content-blind scheduling delay is 38 us
- Content-aware scheduling delay is 87 us
- The routing overhead for each acknowledgement crossing the web switch is 17 us

Performance evaluation: best case



- Three identical requests are directed to the distributed Web server
  - HRW - all the requests are dispatched to the same real server, which can consequently load the requested object from the disk cache (1 miss and 2 hits)
  - RR and LC - the requests are dispatched to three different real servers, which are consequently forced to load objects from the disk (3 misses)

Performance evaluation: realistic conditions

- The performance analysis has been carried out by using:
  - 7 PCs, each equipped with 2 CPUs Pentium II 350 MHz, hard disk EIDE 4GB, 128 MB of RAM, Fast Ethernet NIC
  - interconnected through a Fast Ethernet switch
  - A PC was used as a web switch, while the other 6 computers was used both as
    - servers running the Apache Web server (rel. 1.3)
    - and as clients
  - The SURGE Web traffic generator developed at the Boston University was installed on the clients

Performance evaluation: realistic conditions

- SURGE is able to emulate the behavior of a typical Web user by modeling his on/off time activity sequence
- Differently from other Web benchmarks, SURGE introduces the concept of “User Equivalent” (UE) to capture the notion of throughput
  - Each UE is modeled as a thread executing the loop <load(object), wait(off time)> concurrently with other threads
- The Web content used consists of distinct files replicated on each real server, where the *Zipf* distribution of the object’s popularity was generated assuming 20000 requests for the most popular object

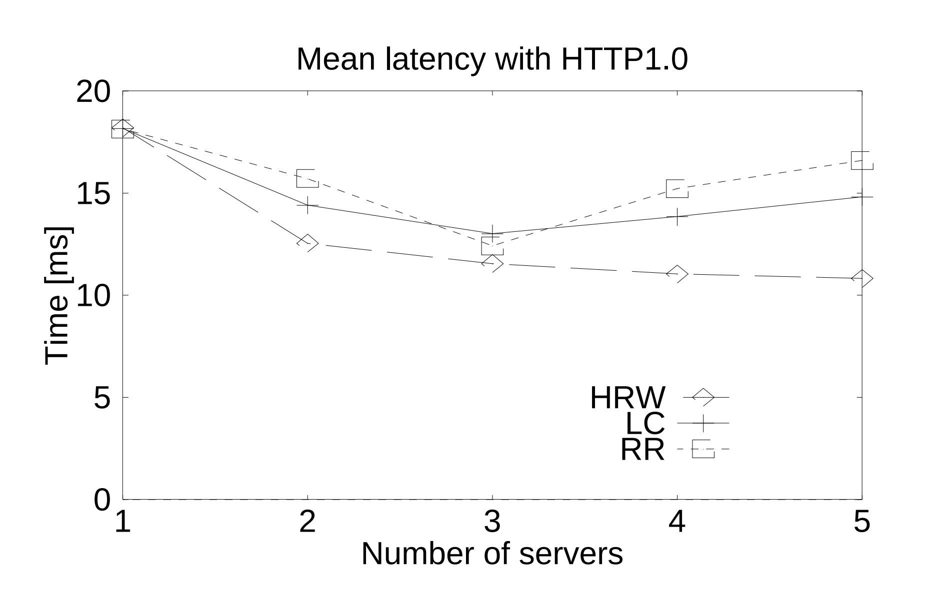
Performance evaluation: realistic conditions

- To measure some basic parameters, such as the sustainable throughput and the mean latency, we used SURGE as a simple benchmark, eliminating the off time and using only one UE
  - This way, requests are sent in sequence and generate a throughput that is the reciprocal of the latency

	Real Servers	Gets/Sec	Total requests	Different requested Objects	Mean size of requested objects [byte]	Mean latency [ms]
HRW					8449	**3,321**
	WS1	91,4166	5485	310		
	WS2	73,1017	4313	331		
	WS3	136,8999	8214	302		
LC					8730	**5,778**
	WS1	56,1147	3423	523		
	WS2	56,6949	3345	519		
	WS3	60,9830	3598	551		
RR					8756	**5,678**
	WS1	59,5423	3513	518		
	WS2	59,5423	3513	532		
	WS3	59,5243	3513	513		

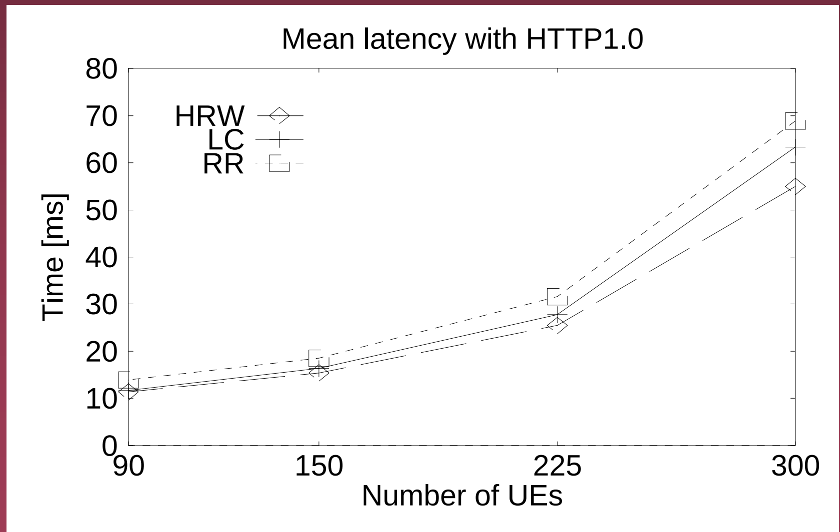
Performance evaluation: scalability

- A further analysis was aimed at characterizing the behavior of HRW when the number of servers grows
- For this test, we used a Web content composed of 700 files (medium size = 32 KB, maximum size = 4096 KB) replicated on a varying number of servers (from 1 to 5) and SURGE ran with 100 UEs for 500 secs, with the on/off model activated

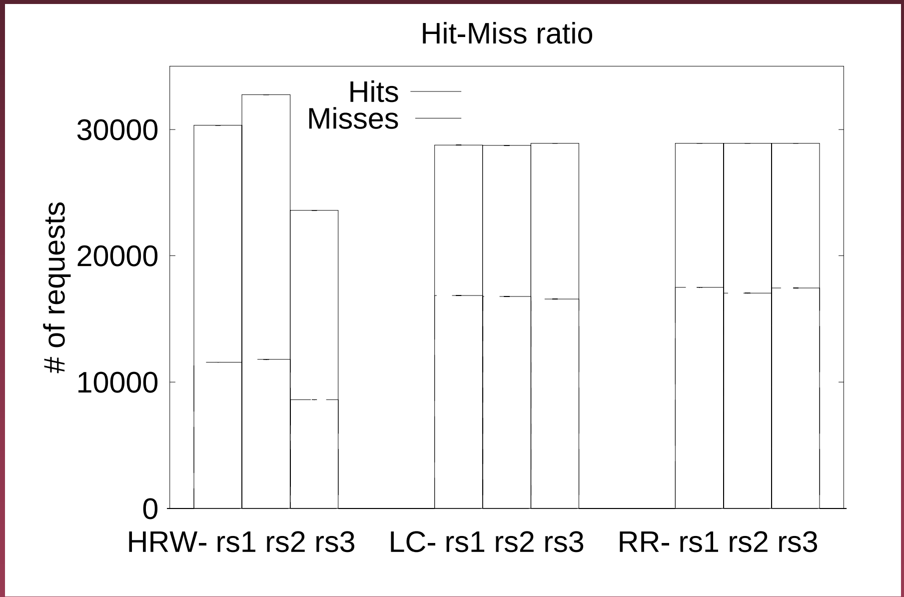


Performance evaluation: worst case

- We chose the configuration characterized by three servers to analyze the behavior of the web switch under high load conditions
  - With this configuration HRW shows a worse behavior compared to the other configurations under the same load conditions
  - We performed a number of tests with a varying number of UEs (from 90 to 300)

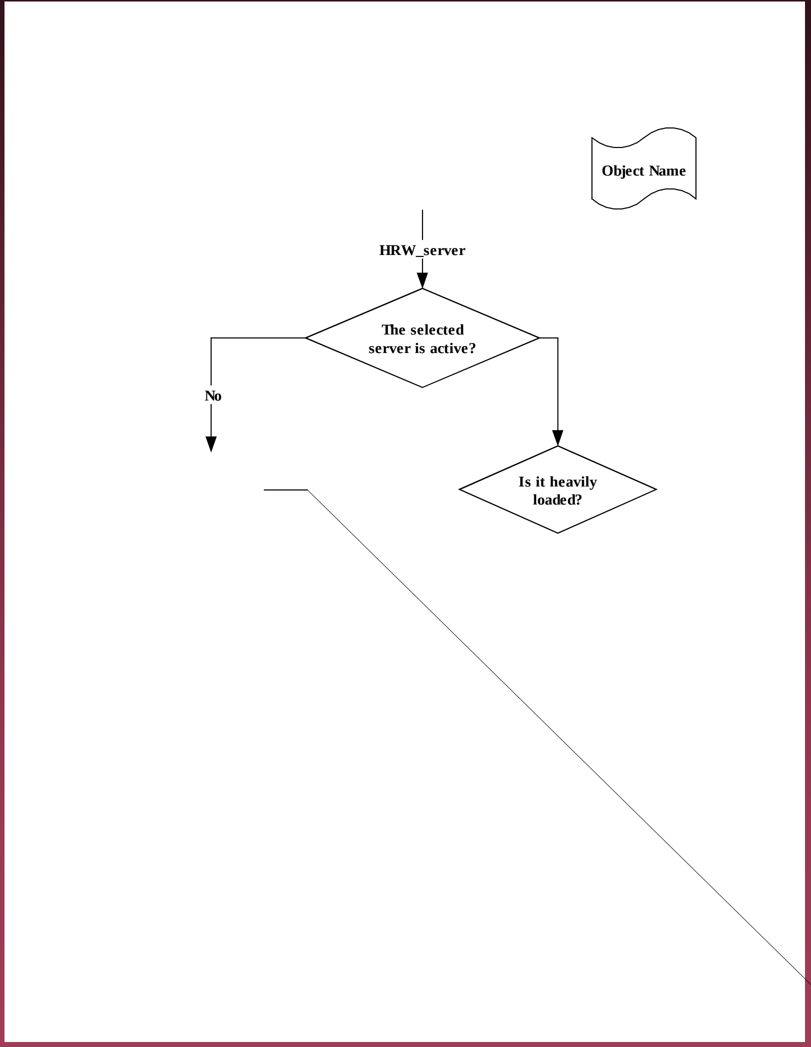


Analysis of log files



- We analyzed the log files of the real servers with a cache simulator based on the LRU policy
- Using HRW, the fraction of requests that generates hits is higher than those observable with LC and RR
- HRW generates an unbalancing of requests due to the different popularity of web objects belonging to the web site

A hybrid locality-aware algorithm based on cache prediction



Performance improvements

- LACP is able to execute in different configurations:
  - Pure HRW
    - when real server load <= Tlow
  - Pure LC
    - when real server load >= Thigh
  - Pure Cache Prediction scheme (CP)
    - when Tlow < real server load < Thigh
- With 300 Ues and three web servers, the latency measurements were those reported in the table below

# test	Tlow	Thigh	Algorithm	Latency [ms]
1	0	60000	CP	58,781
2	60000	60000	HRW	54,965
3	0	0	LC	63,292
4	**4000**	**4300**	**LACP**	46,106
5	3500	4000	LACP	48,358
6	4300	5000	LACP	49,971
7	4000	4500	LACP	46,875

Conclusions

- A variant of TCP-handoff for the dispatching of HTTP requests in clustered Web servers has been presented

- The implementation of the mechanism requires a change in the network module of an OS of both the web switch and real servers
- To evaluate the proposed mechanism, the *Highest Random Weight* name-based scheduling algorithm was implemented and tested
  - The test bed was composed of a cluster of machines interconnected by a Fast Ethernet network and affected by a HTTP traffic locally generated by the SURGE traffic generator
- The performance results suggested a further improvement
- So, a hybrid locality-aware algorithm based on cache prediction was defined and implemented
  - This algorithm improves the performance of the HRW one

Future work

- We intend to:
  - port the TCP-handoff variant implementation on the kernel 2.4.x in which the netfilter framework will be used
  - individuate a criterion for defining the Tlow and Thigh thresholds
  - extend the proposed dispatching mechanism to split of TCP connections over different real servers, necessary to guarantee a higher hit/miss ratio when the HTTP/1.1 is used
  - explore specific content-aware algorithms for retriving dynamic Web pages and multimedia contents