ETL Queues for Active Data Warehousing

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Forecast

- Active DW refers to the idea of updating the DW with new contents asap
- We demonstrate that we can employ **queue theory to predict the behavior** of the refreshment process of an Active DW
- We discuss implementation issues in order to achieve minimal system overhead and high freshness of data

Contents

- Problem description
- System Architecture & Theoretical Analysis
- Experiments
- Conclusions and Future Work

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Active Data Warehousing

- Traditionally, data warehouse refreshment has been performed off-line, through Extractction-Transformation-Loading (ETL) software.
- **Active Data Warehousing** refers to a new trend where data warehouses are updated as frequently as possible, to accommodate the high demands of users for fresh data.
- Issues that come up:
  - How to design an Active DW?
  - How can we implement an Active DW?

Issues and Goals of this paper

- Smooth upgrade of the software at the (legacy) source
  - Minimal modification of the software configuration at the source side.
- Minimal overhead of the source system

- No data losses are allowed
- Maximum freshness of data
  - The response time for the transport, cleaning, transformation and loading of a new source record to the DW should be small and predictable

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- Stable interface at the warehouse side
  - The architecture should scale up with respect to the number of sources and data consumers at the DW
  - If possible, cover issues like checkpointing, index maintenance, etc.

Contributions

- We set up the architectural framework and the issues that arise for the case of active data warehousing.
- We develop the theoretical framework for the problem, by employing queue theory for the prediction of the performance of the system.
  - We provide a taxonomy for ETL tasks that allows treating them as black-box tasks.
  - Then, standard queue theory techniques can be applied for the design of an ETL workflow.
- We provide technical solutions for the implementation of our reference architecture, achieving the aforementioned goals
- We prove our results through extensive experimentation.

Related work

- Obviously, work in the field of ETL is related
  - must be customized for active DW
- Streams, due to the nature of the data
  - still, all R.W. is on continuous queries, no updates
- Huge amount of work in materialized view refreshment
  - orthogonal to our problem
- Web services
  - due to the fact that in our architecture, the DW exports W.S.'s to the sources

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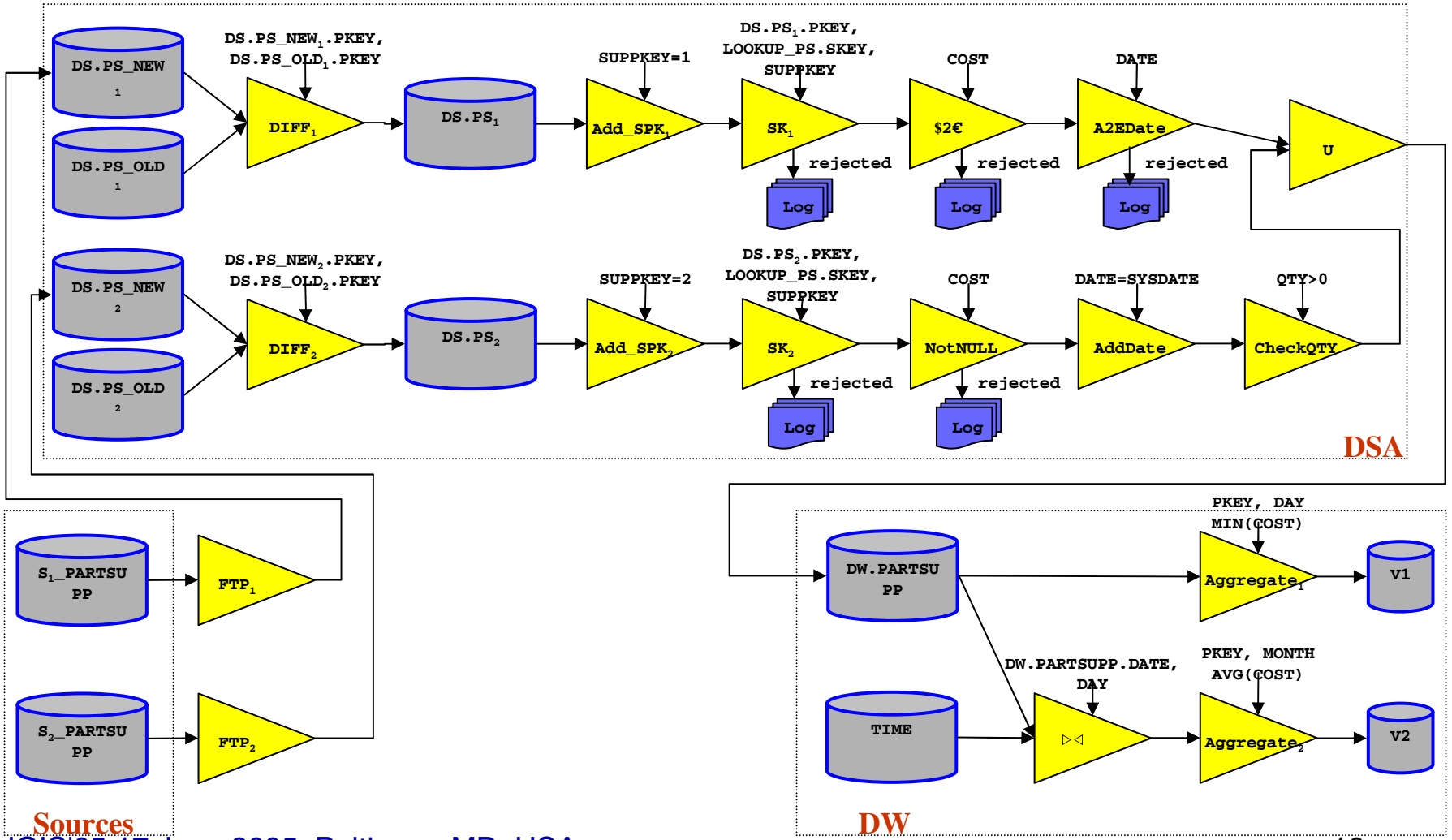
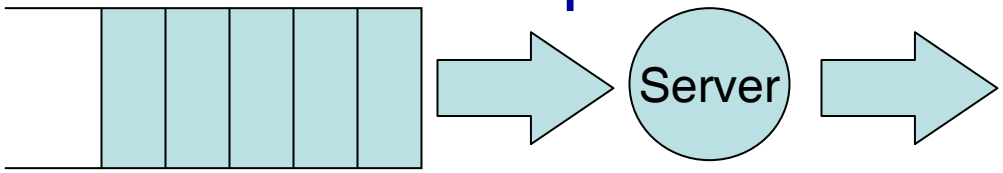
ETL workflows



Queue Theory for ETL

- We can model various kinds of ETL transformations as queues, which we call ETL queues
- Each queue has an incoming arrival rate λ and a mean service time 1/μ

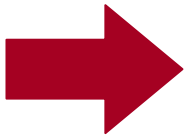


- Little's Law: N= λ*T
- Based on their statistical properties, queue characteristics can be estimated
  - E.g., M/M/1 queue (Poisson arrivals)
    - Mean response time W=1/(μ-λ)
    - Mean queue length L=ρ/(1 - ρ), ρ=λ/μ

Queue Theory for ETL

- Queues can be combined to form queue networks
- Jackson networks: networks were each queue can be solved independently (under reasonable constraints)

- How can we use queue theory to predict the behavior of the Active Data Warehouse?



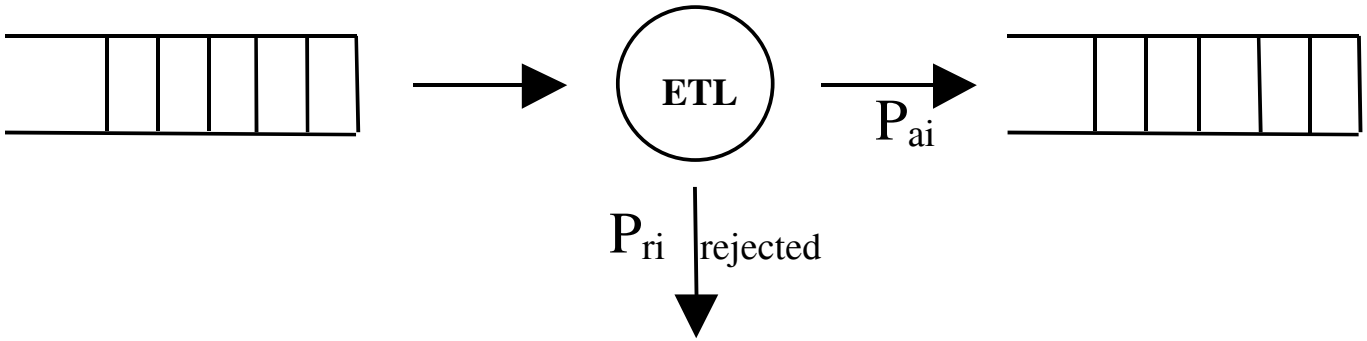
How to predict the behavior of the Active Data Warehouse

1. Compose ETL queues in a Jackson network to simulate the implementation of the **Active Data Staging Area (ADSA)**
2. Then, solve the Jackson network and relate the parameters of ADSA, specifically:
   - Source arrival rate (i.e., rate or record production at the source)
   - Overall service time (i.e., time that a record spends in the ADSA)
   - Mean queue length (i.e., no. of records in the network)

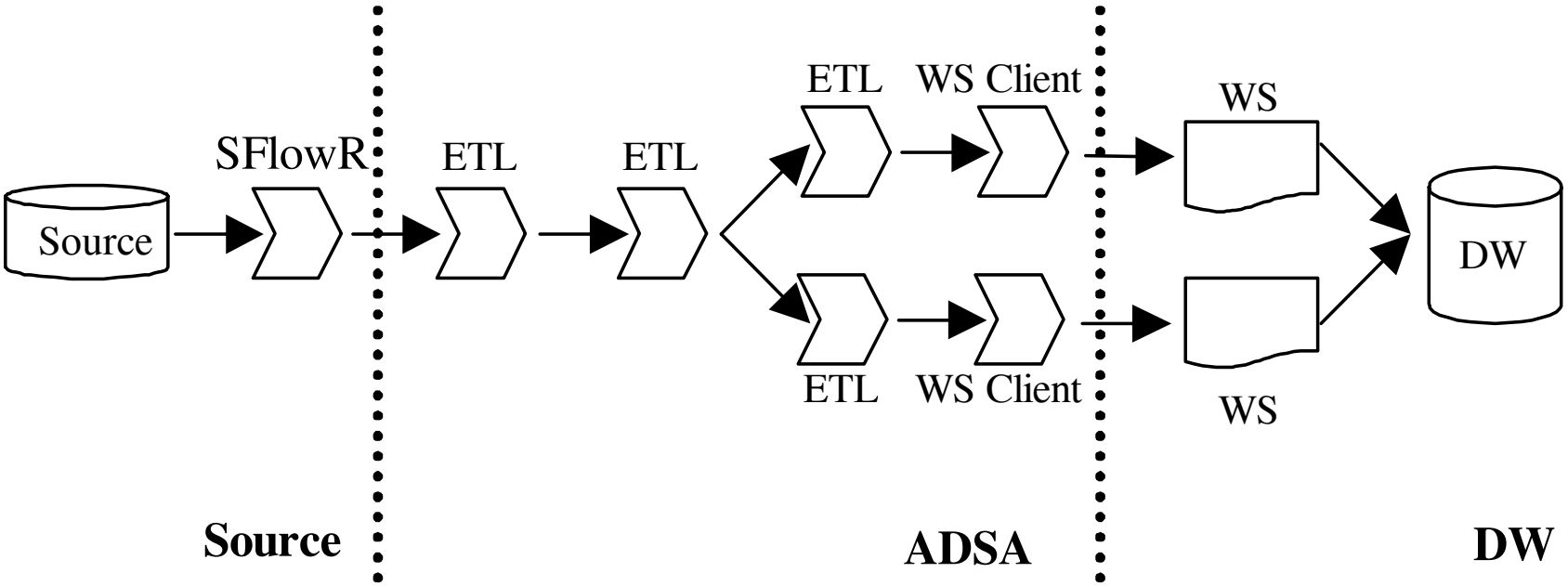
Taxonomy of ETL transformations

- Filters
- Transformers
- Binary Operators

- Generic model



System Architecture



System Architecture

- Source Flow Regulator (SFlowR): compiles changes in blocks and propagates them
- Active Data Staging Area (ADSA)
  - Performs all the ETL tasks
  - Can act as a regulator for the flow towards the DW
- ETL queues: periodically check their queue and process incoming blocks
- WS-client: each WS needs a client to invoke it (also acting as a WS-FlowR)
- Web Service: one per DW table.
- WS/WS-client: can be used for load-balancing, checkpointing, …

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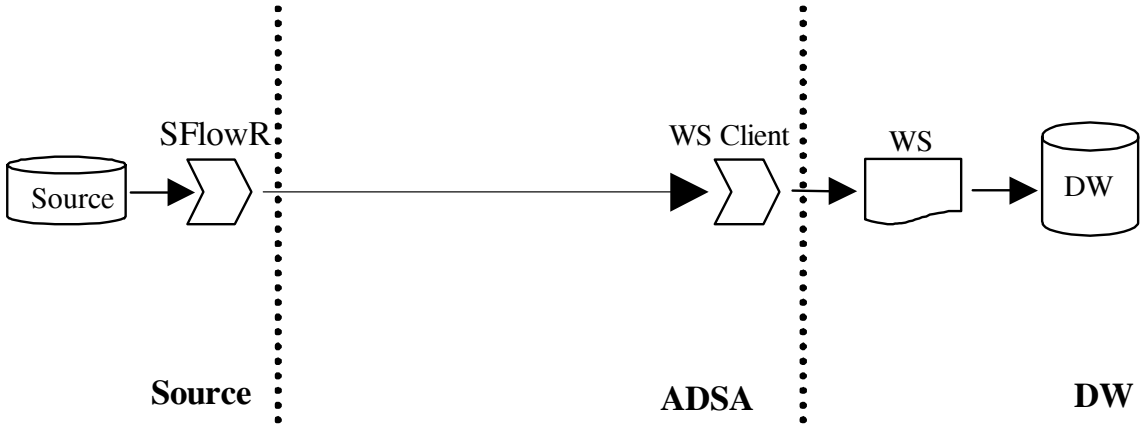
Experimentation environment

- Source: an application in C that uses an ISAM library
- ADSA implemented in Sun JDK 1.4
- Web Services platform:
  - Apache Axis 1.1 [AXIS04]
  - Xerces XML parser
  - Apache Tomcat 1.3.29
- DW implemented over MySQL 4.1
- Configuration:
  - Source: PIII 700MHz with 256MB memory, SuSE Linux 8.1
  - DW: Pentium 4 2.8GHz with 1GB memory, Mandrake Linux, ADSA included
  - Department's LAN for the network
- Source operates at full capacity

First set of experiments

- A first set of experiments over a simple configuration, to determine fundamental architectural choices
- Issues
  - Smooth upgrade of the source software
  - UDP vs TCP
  - Source Overhead
  - Data delay
  - Topology



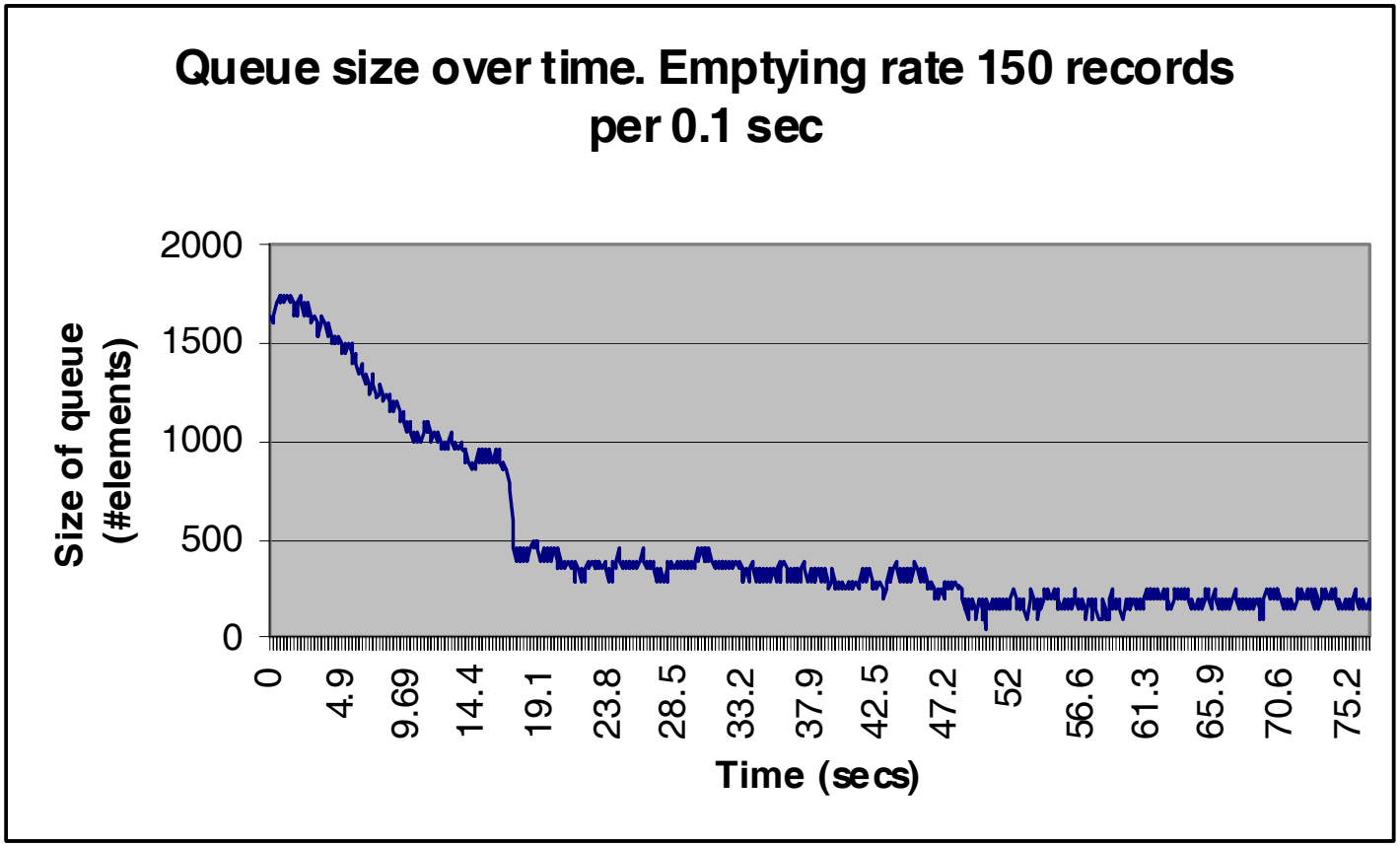
Experimentation results

- Smooth upgrade: not more than 100 lines of library code modified
- UDP resulted in 35% data loss, due to ADSA overflow => TCP a clear choice
- Source overhead is highly dependent on row blocking:
  - Source overhead is 1.7% with a source flow regulator, vs 34% without
  - WS mode (blocking vs non-blocking) has no effect
  - Medium size packets seem to work better

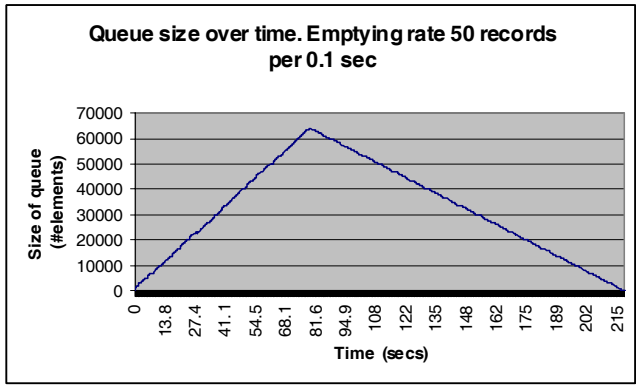
Data Freshness

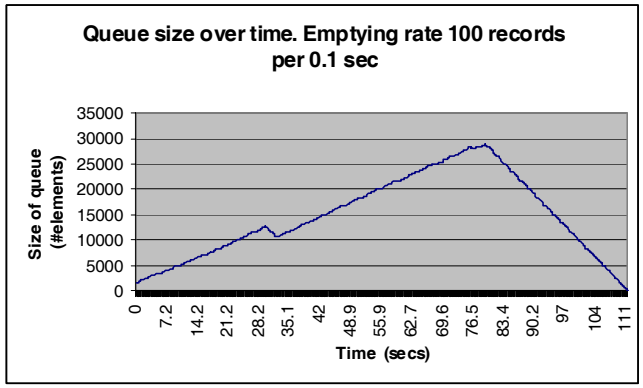
- We count the time to carry all records from source to DW
- We empty the ADSA with 3 policies:
  - Immediate transport
  - We simulate a slower ADSA by removing 50, 100, 150, 200, 250 and 300 records from the queue every 0.1 sec
  - We remove 500, 1000, 1500, 2000, 2500 and 3000 records every 1 sec
  - Source max rate is about 1250 records / sec
- Findings:
  - Small package sizes result in small delays
  - There is a threshold (the source rate) underneath which the queue explodes
  - We can achieve data freshness time equal to data insertion time when we *continuously* empty *a* small size queue

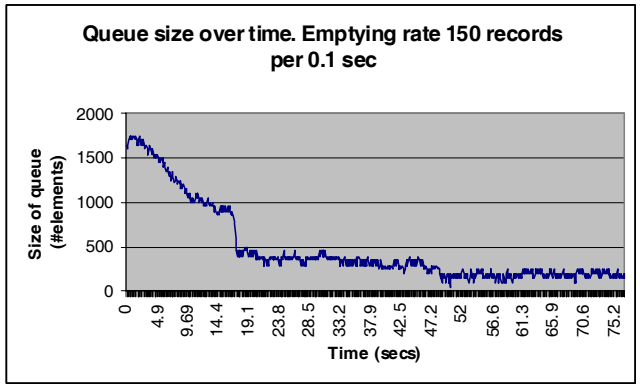
Data Freshness

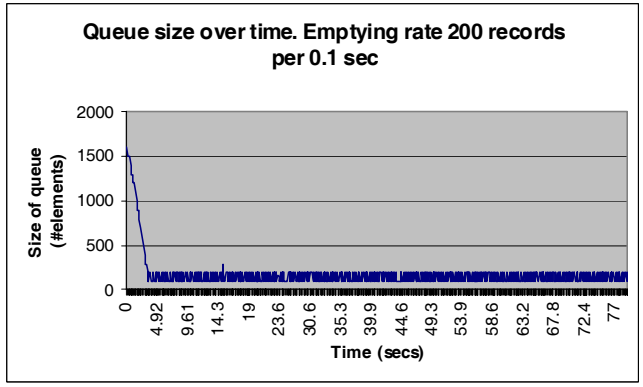


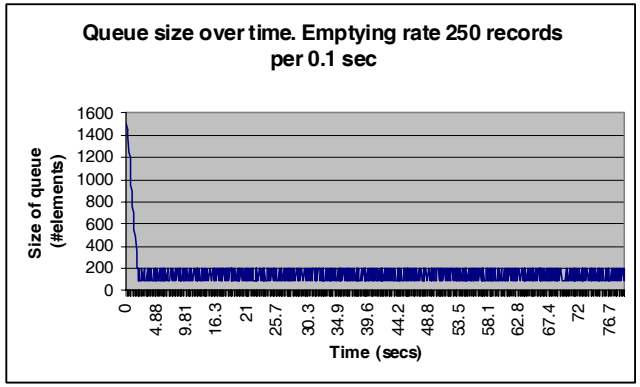
Data Fresh-ness

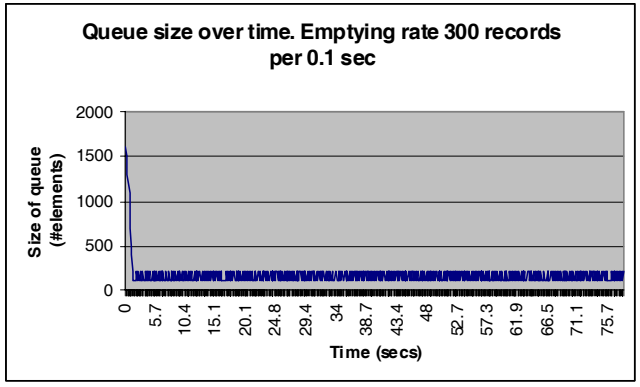




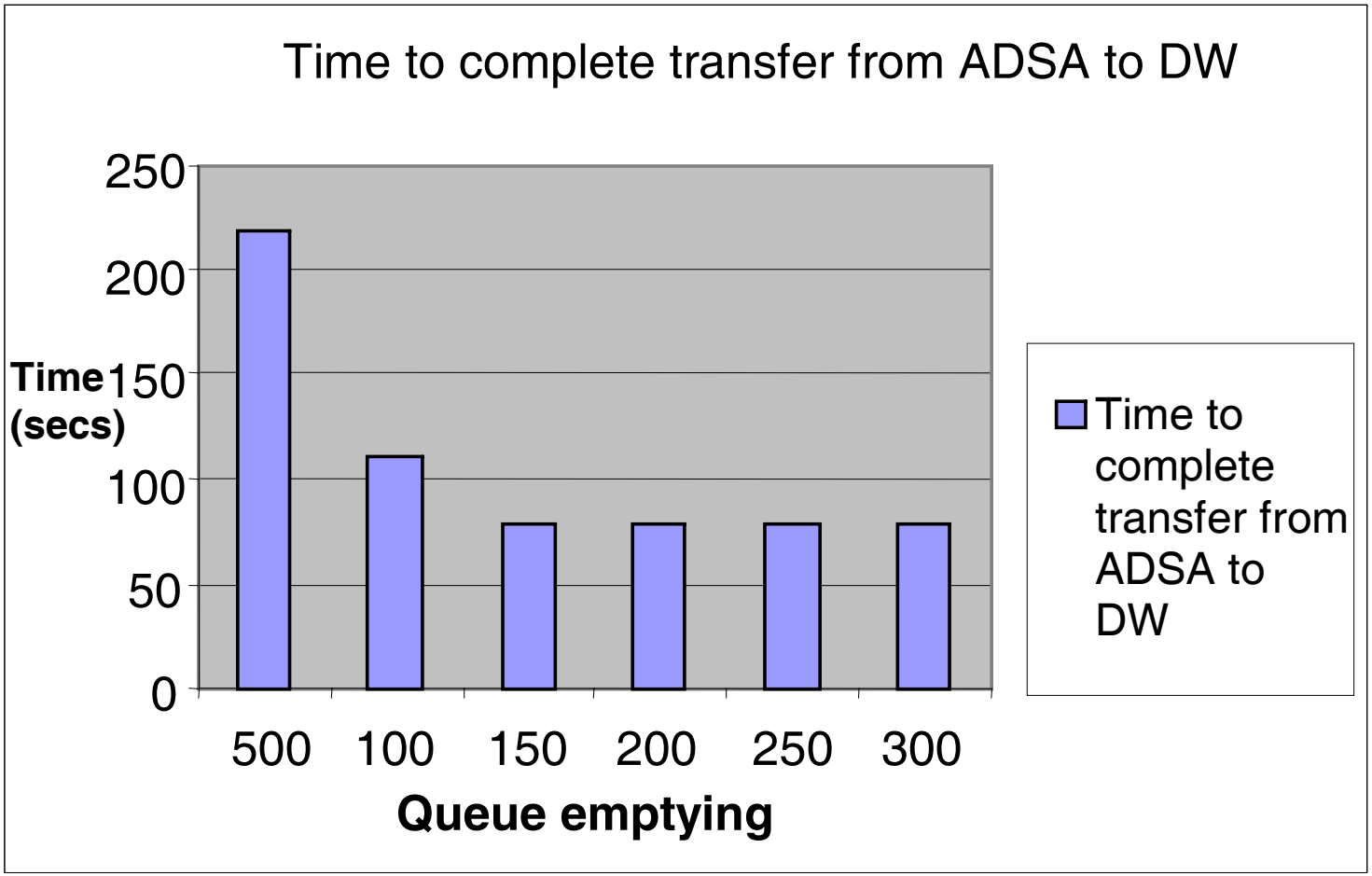








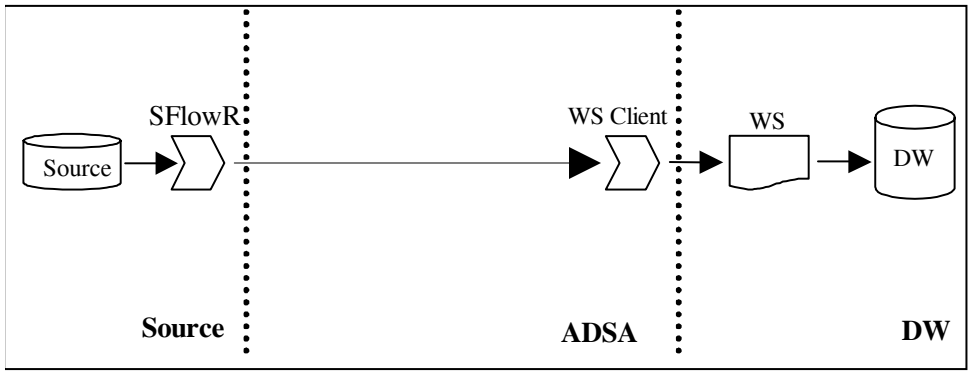
Data Freshness



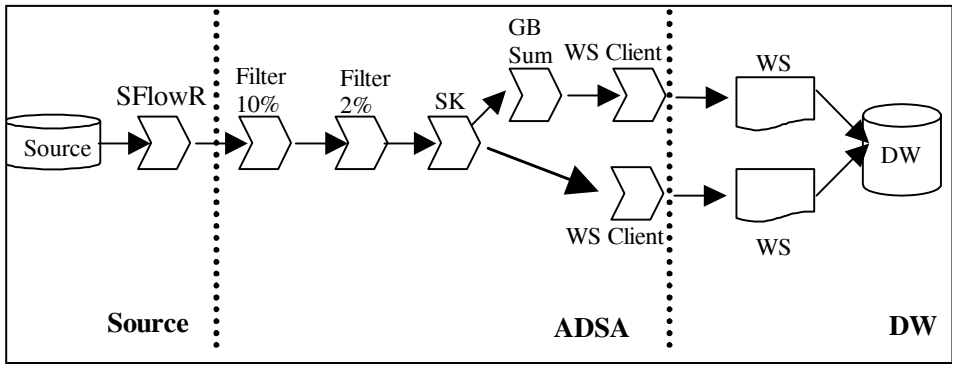
Experiments including transformation scenarios

- We enrich the previous configuration with several ETL activities in the ADSA
- Based on the previous, we have fixed:
  - 2-tier architecture, ADSA at the DW
  - Source Flow Regulation with medium size packages
  - TCP for network connection
  - Non-blocking calling of DW WS's

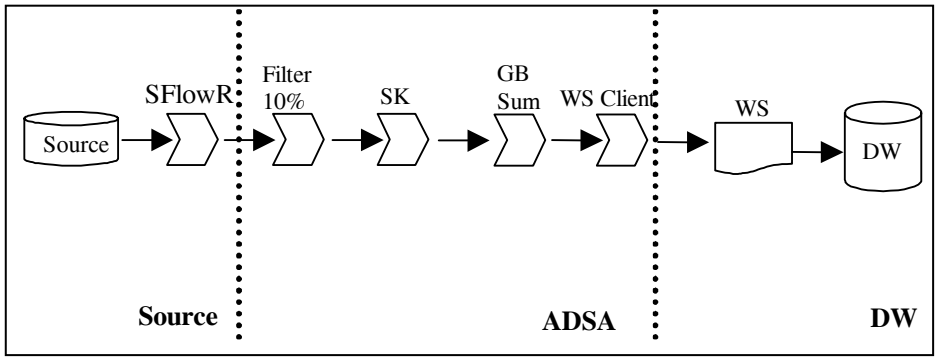
Scenarios to measure data freshness



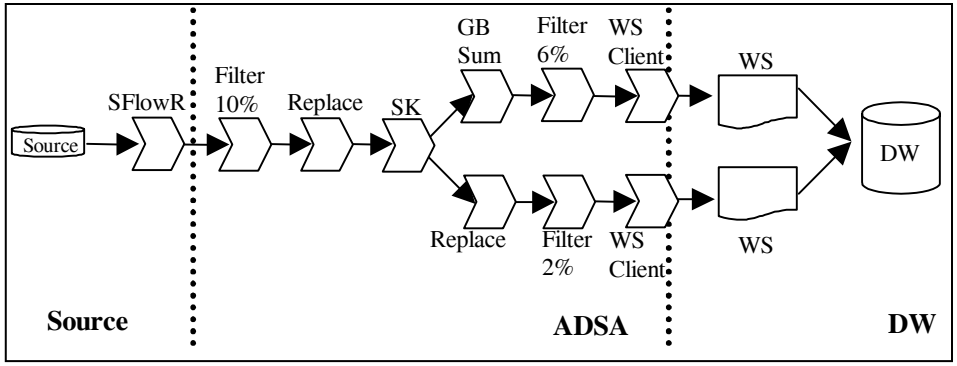
(a)



(c)



(b)



(d)

Goals of the experiments

- Steadiness of the system
  - System is steady whenever service rate is higher than arrival rate; transient effects disappear
- Source overhead
  - Medium size blocking is still a winner
- Throughput for ADSA
  - The ADSA is only one packet behind the source
  - Avg. delay per row ~0.9 msec for all scenarios
- Success of theoretical prediction
  - Half a packet underestimation

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Conclusions

- We can **employ queue theory to predict the behavior of an Active ETL process**
- We have proposed an architectural configuration with
  - Minimal source overhead
  - No effect on the source due to the operation of an ADSA
  - No packet losses, due to the usage of TCP
  - Small delay in the ADSA, especially if row blocking in medium size blocks is used

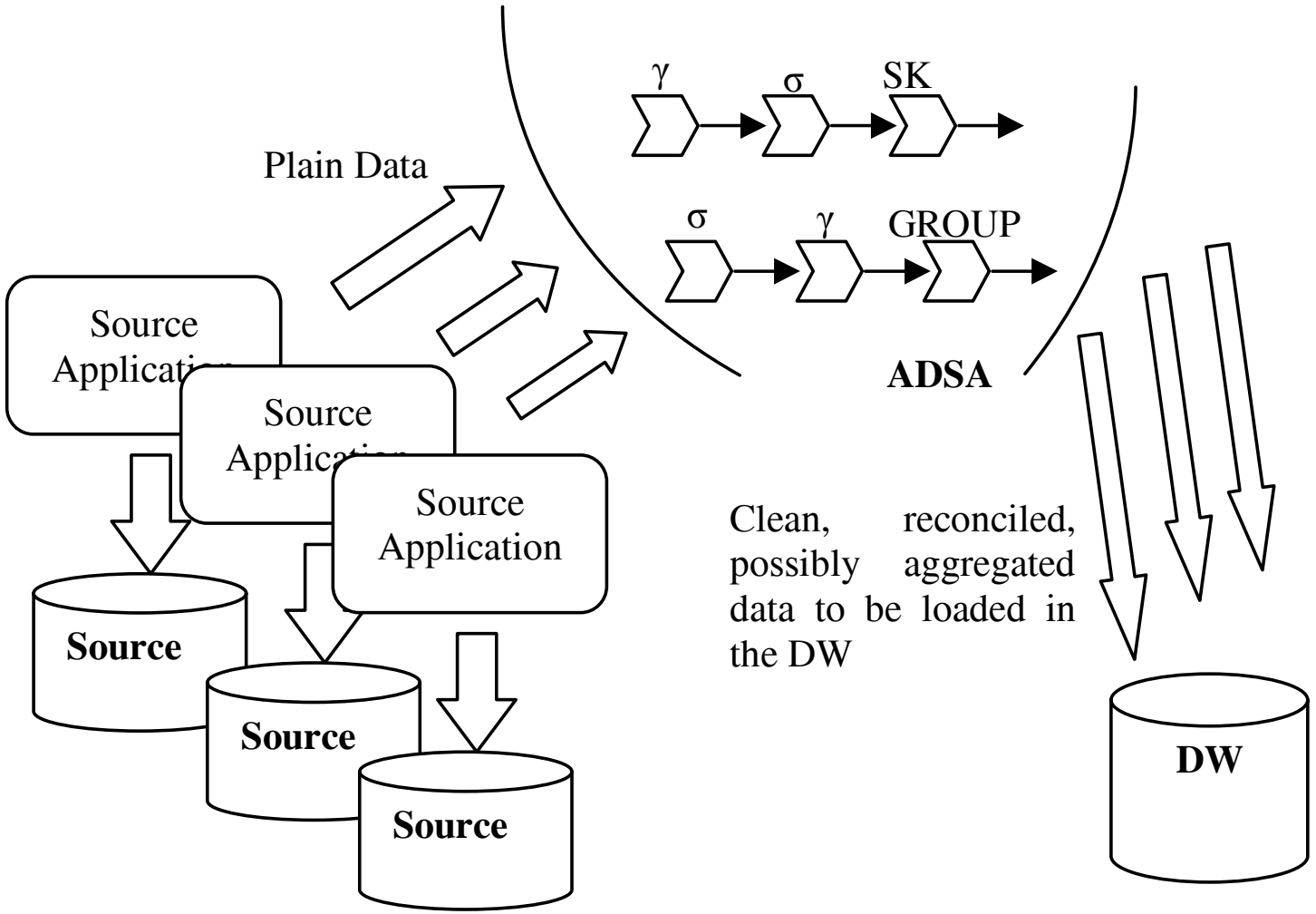
Future Work

- Combine our configuration with results in the optimization of ETL processes (ICDE'05)
- Fault tolerance
- Experiment with higher client loads at the warehouse side
- Scale-up the number of sources involved

Thank you!

Backup Slides

Grand View


γ
σ
SK
Plain Data
σ
γ
GROUP
Source Application
Source Application
Source Application
ADSA
Clean, reconciled, possibly aggregated data to be loaded in the DW
Source
Source
Source
DW

Jackson's Theorem and ETL queues

Jackson's Theorem. If in an open network the condition $\lambda i < \mu i \cdot mi$ holds for every $i \in \{1, ..,N\}$ (with *mi* standing for the number of servers at node *i*) then the steady state probability of the network can be expressed as the product of the state probabilities of the individual nodes:

$$\pi (k_1,\ldots, k_N) = \pi_1(k_1)\pi_2(k_2)\ldots \pi_N(k_N)$$

Therefore, we can solve this class of networks in four steps:

- Solve the traffic equations to find λi for each queuing node *i*
- Determine separately for each queuing system *i* its steady-state probabilities $\pi_i(k_i)$
- Determine the global steady-state probabilities $\pi (k_1,\ldots, k_N)$. Derive the desired global performance measures.
- From step 1, we can derive the mean delay and queue length for each node.

Source Code Alterations

Original Routine	Altered Routine

Open_isam_File(){
…
opening_isam_file_commands
…
}
	Open_isam_File(){
	…
	opening_isam_file_commands
	…
	if(open==success)
	DWFlowR_socket_open()
	}

Write_record_to_File(){
…
insert_record_commands
…
}
	Write_record_to_File(){
	…
	insert_record_commands
	…
	if(write==success)
	write_to_SFlowR()
	}

Close_isam_File(){
…
closing_isam_file_commands
…
}
	Close_isam_File(){
	…
	closing_isam_file_commands
	…
	if(close==success)
	DWFlowR_socket_close()
	}

First set of experiments

Data Freshness

- We count the time to carry all records from source to DW
- We empty the ADSA with 3 policies:
  - Immediate transport
  - We simulate a slower ADSA by removing 50, 100, 150, 200, 250 and 300 records from the queue every 0.1 sec
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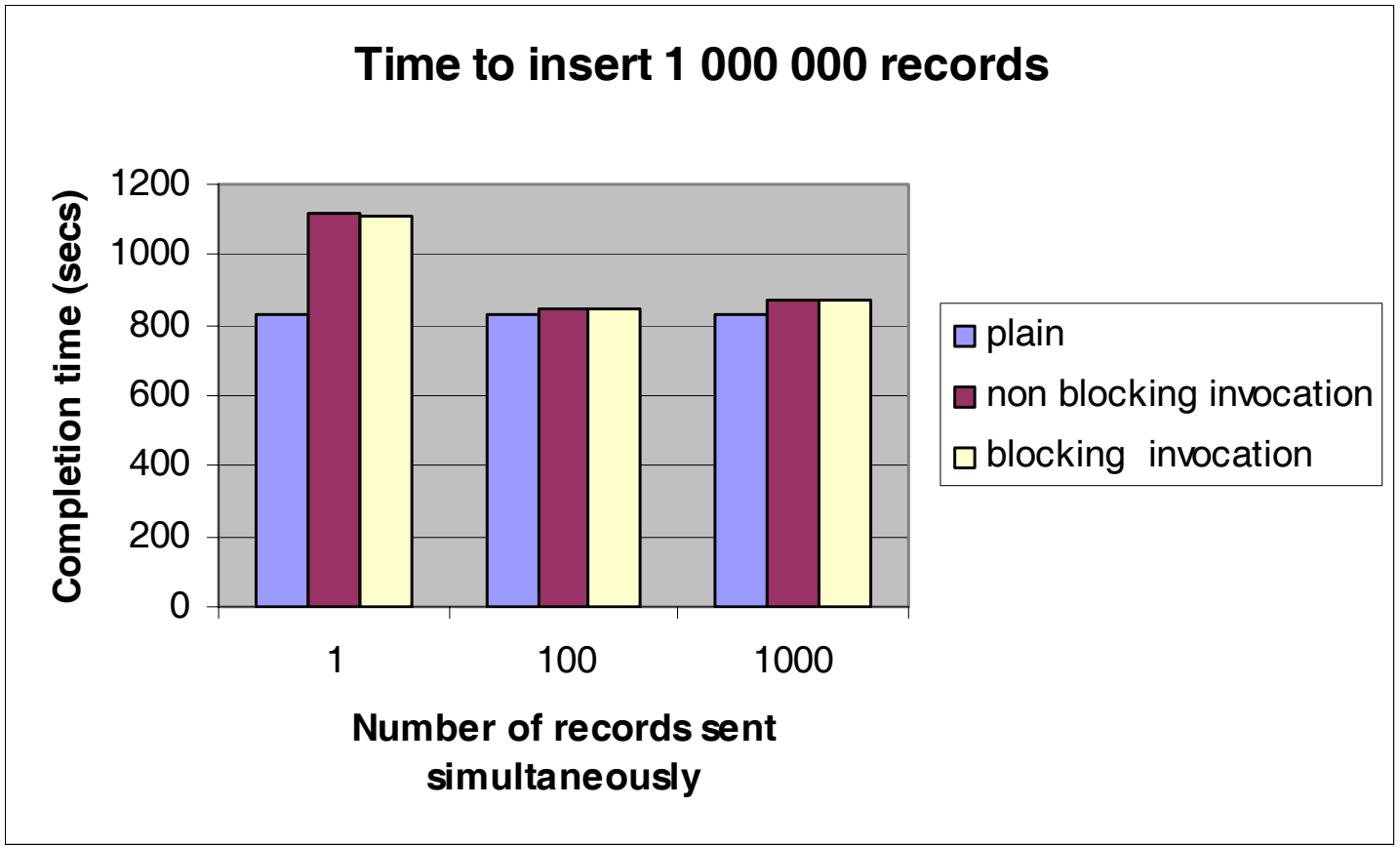
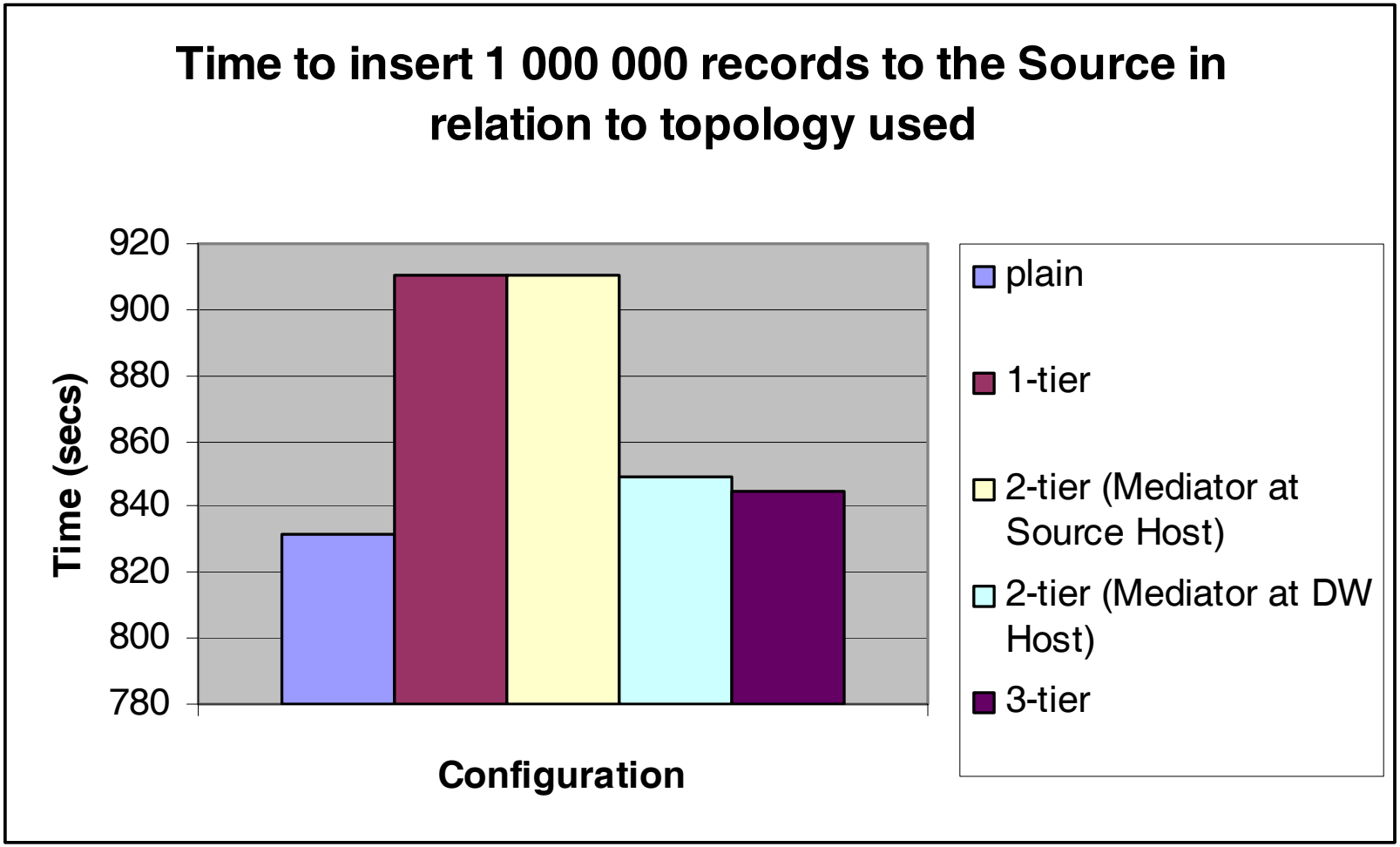
Source overhead

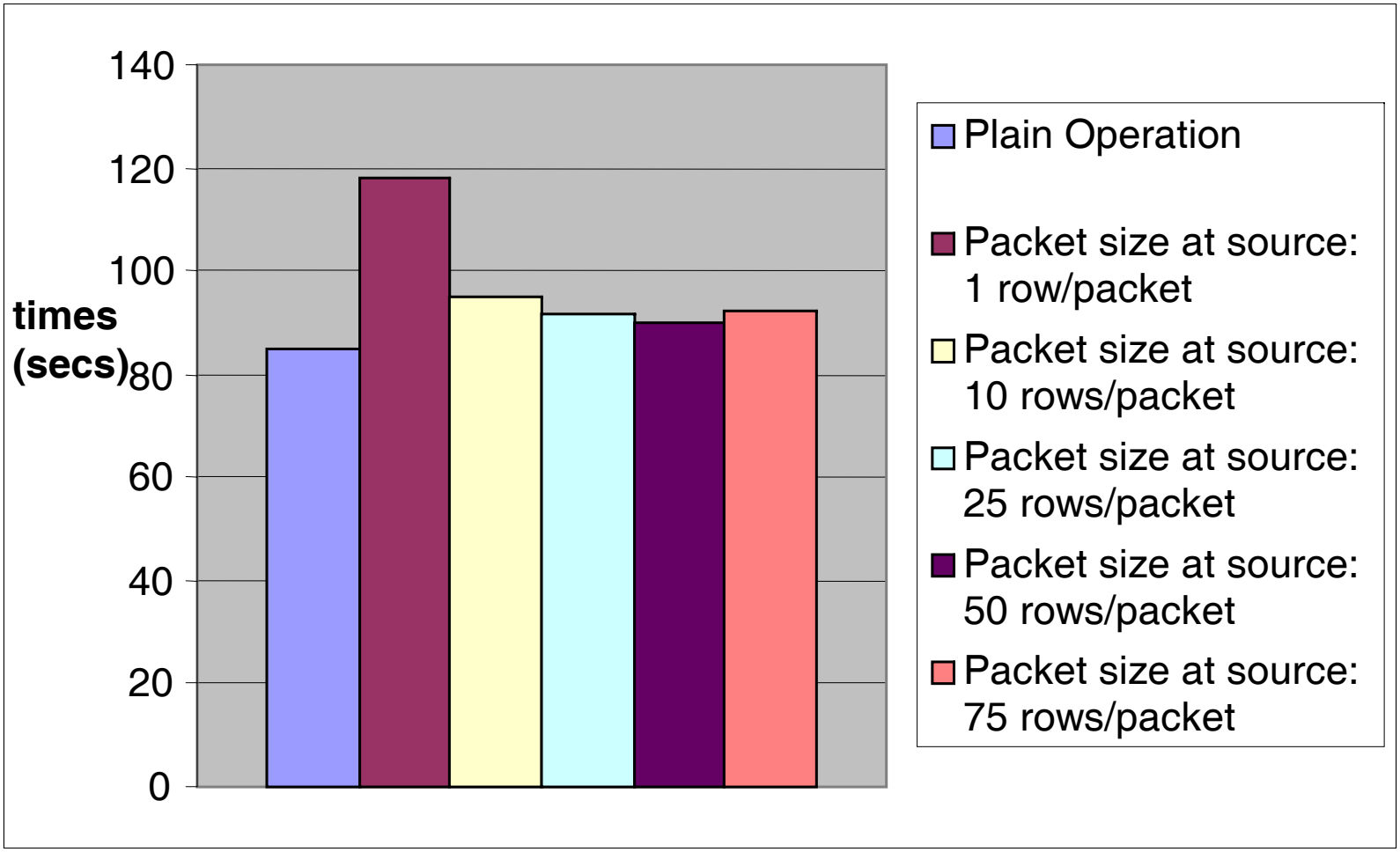


Topology and source overhead

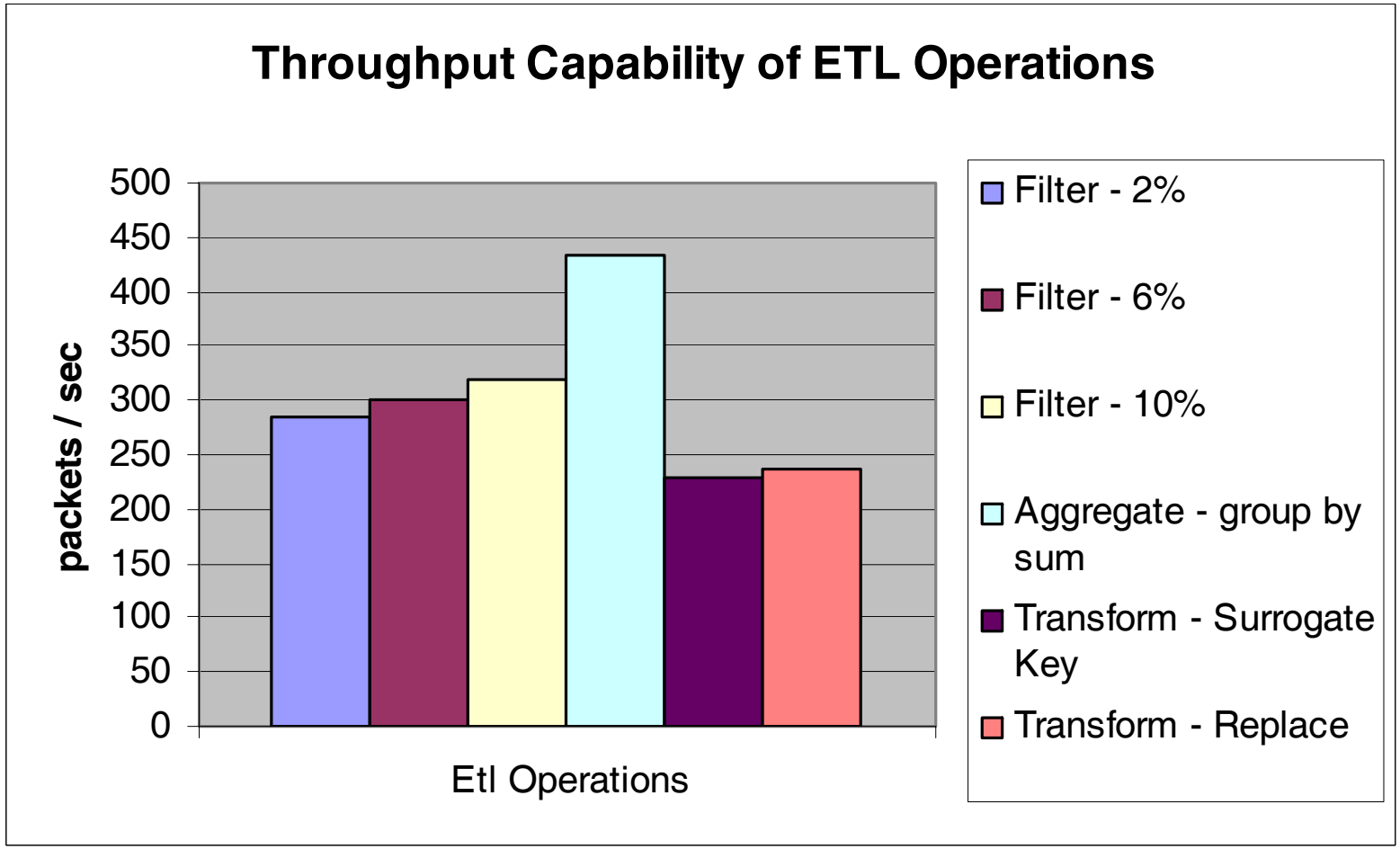


Second set of experiments

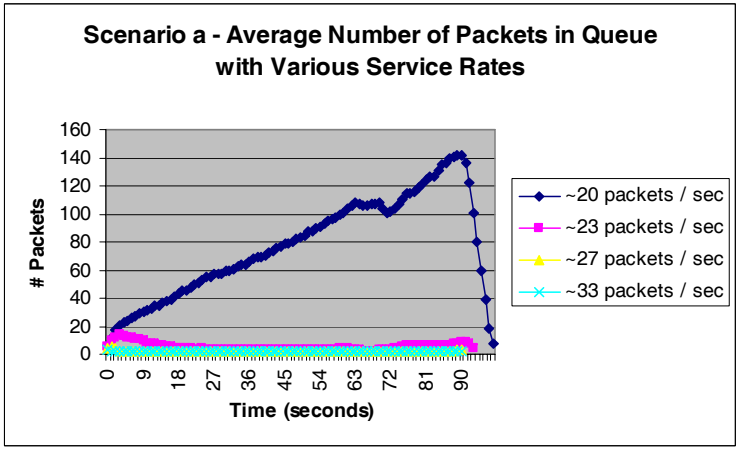
Source overhead

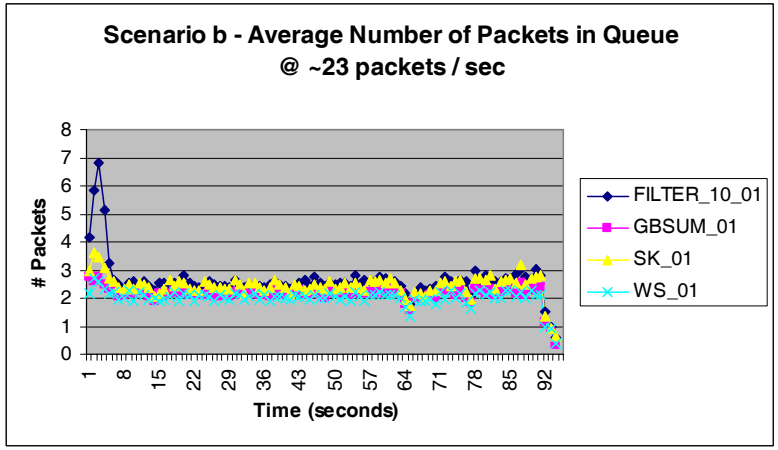


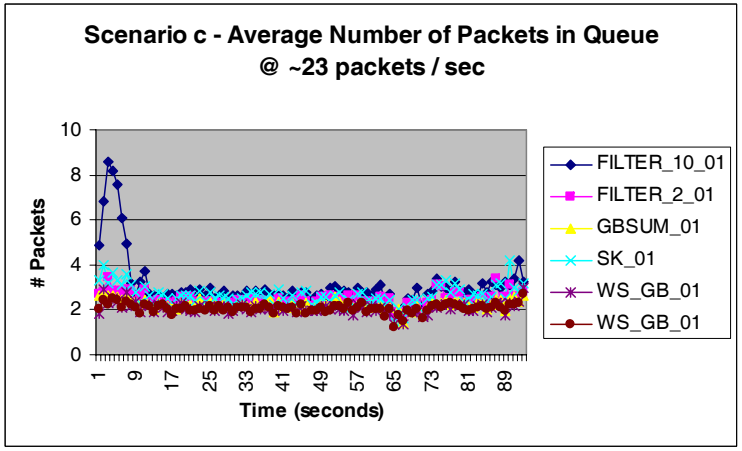
Throughput for ETL operations

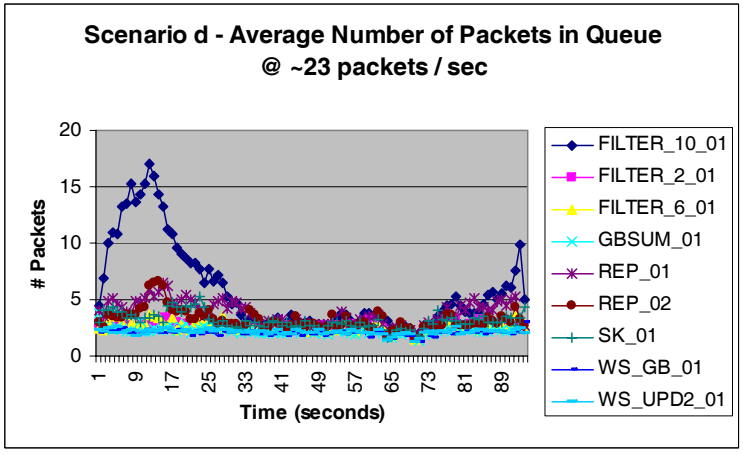


Scenarios to measure data freshness

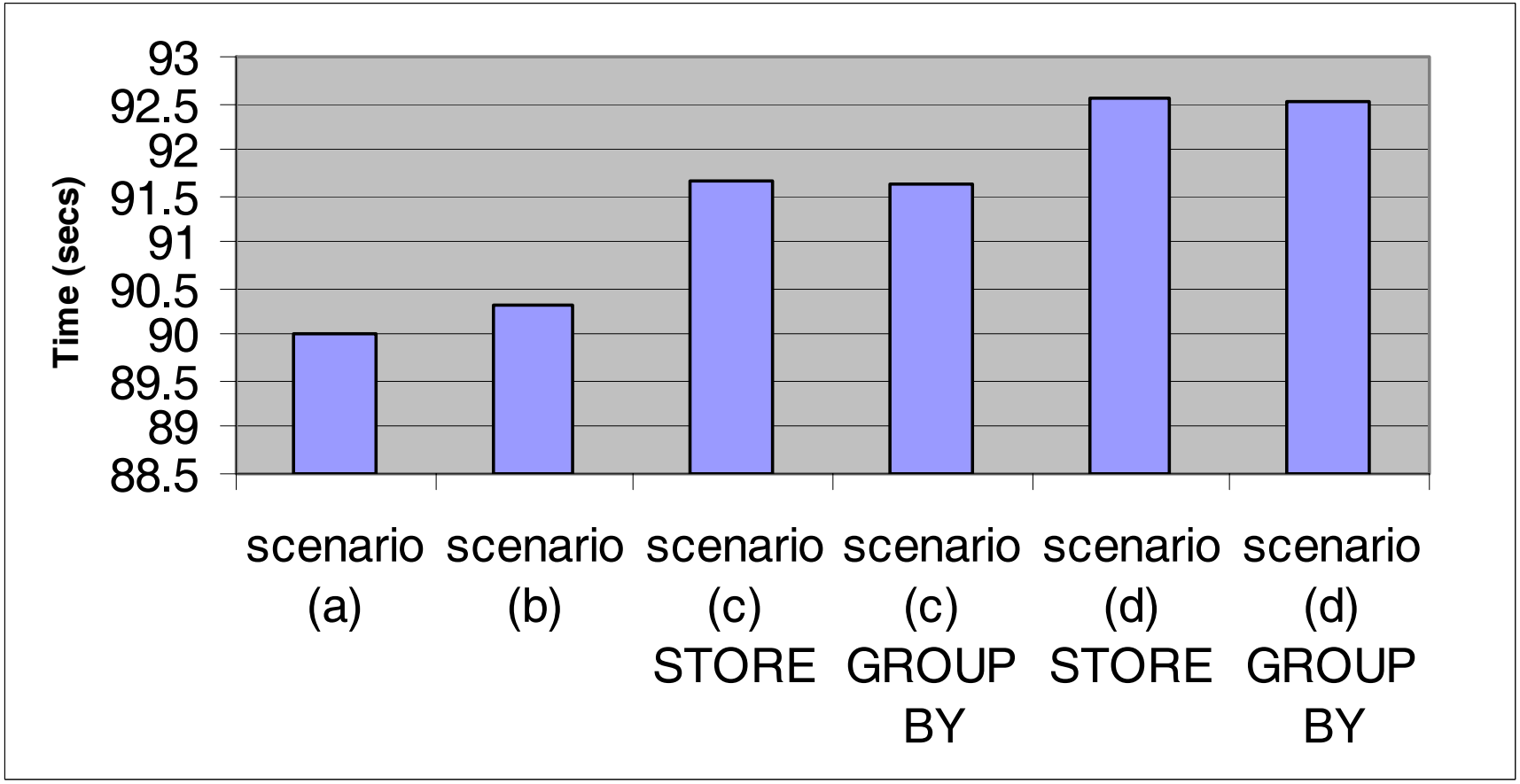








Data Delay


Time (secs)
93
92.5
92
91.5
91
90.5
90
89.5
89
88.5
scenario (a)
scenario (b)
scenario (c) STORE
scenario (c) GROUP BY
scenario (d) STORE
scenario (d) GROUP BY

Theoretical prediction vs. actual measurements of average queue length for scenario (c) in packets

	Measured	Theoretical Prediction	Difference
FILTER_10_01	0.160	0.056	0.104
FILTER_02_01	0.134	0.047	0.087
SK_01	0.154	0.054	0.100
GB_SUM_01	0.137	0.048	0.089
WS_GB	0.091	0.031	0.059
WS_GB_UPD	0.100	0.035	0.066

Theoretical Predictions and Actual Measurements

- In most cases, we underestimate the actual queue size by half a packet (i.e., 25 records)
- We overestimate the actual queue size when we simulate slow servers, esp. in the combination of large timeouts and large packets
- Reasons for the discrepancies:
  - Simulation of slower rates through timeouts
  - Due to the row-blocking approach, the granule of transport is a single packet