# On Respecting Interdependence Between Queueing Policy and Message Value

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## Introduction

As electronic messaging grew, it quickly became evident that some messages were more time critical than others. With this realization, a message priority scheme was instituted. Military torn-tape relays typically used four or five levels of priority, from low priority to high, such as *routine*, *priority*, *immediate* and *flash*. It was a general tenet of operation, that once a priority was assigned by the originator, it was almost without exception invariant over the message's lifetime in transit through the communications network.

As the operational and conflict bandwidth increased as weaponry became more and more sophisticated, and as command and control messages started to grow in volume and compete with potentially shrinking transport bandwidth, it became clear that we needed to focus on two considerations:

- First, it became clear that various classes of data messages have values that change over time. So long as there is sufficient communications capacity, these changing values are of academic interest only. But in those situations where capacity becomes stressed or degraded to the point where a message's expected stay in queue is significant compared to the time scale of its value dynamics, there is a real need to consider reprioritization. To further complicate matters, a message's value is often not intrinsic but rather depends upon other messages. There has been some very good analysis concerning optimal communications server allocation, and there have been some general results respecting the optimal serving of message queues based on fixed cost functions, but the general problem has remained open.
- Second, it has become clear that data communications cannot be practiced by itself but rather must be crafted as a *coequal system's function* with computation. The two are inextricably linked, and therefore optimization goals should reflect the synergy that can and must be realized through their linkage.

Recent history has shown that these considerations are at, or moving toward, common validity. System initiatives such as SDI[1] and various "operate through" scenarios such as what used to be referred to as "trans-SIOP"[2] planning have motivated the cause.

The need for dynamic reprioritization can be indicated for a number of cases. One of the most obvious of these concerns the basic variable of *time*. It is hardly a surprise that a message's value might change with time to delivery. The first thing that comes to mind is, perhaps, a decrease in utility of the message with time. The utility may degrade gradually or suddenly. The value of a message may, however, be considered to increase. For example, if a message of threat warning remains in queue with some specified property which is tied to the message's value, it may behoove us to act on that message's increased value and force the message from queue and on to its destination as the threat becomes increasingly imminent.

Another, more complex case, involves a measure of value that is defined by other messages in queue, or already sent, *or expected*. This is a very difficult to analyze case in general but one which we expect to grow in importance and this is the case which we illustrate by example in this paper. It is the type network question that, we feel, will be best handled by future work in the discipline known as *Active Networks* as its most general answer may well be provided by a communications paradigm in which queues and other conventional network elements are replaced by objects that are aggregations in space and time of interacting packets whose entelechy is according to a genetically engendered teleological nisus.

### Example 1 — A Package Delivery Service

Consider a package delivery service that produces value by on-time pick-up and delivery of packages. Depicted in Figure 1 is a summary of the instant situation. At "time zero" there is a package collection vehicle loaded with packages. These packages will be worth $D to the service if delivered on time, otherwise $0. There are two messages to be sent to the package collection vehicle. These two messages are:

- The **S** message informing the package collection vehicle that Airport 1 is closed and that the package delivery vehicle must go to Airport

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[1] SDI: Strategic Defense Initiative or "Star Wars"

[2] SIOP: Single Integrated Operational Plan or the coordination of all strategic nuclear weapons deployment in wartime under the direction of the Joint Strategic Target Planning Staff (JSTPS)

2 to deliver its packages to an aircraft that leaves in 45 minutes from time zero.

- The **P** message that there is a package waiting for pickup 5 minutes away from the package collection vehicle's position at time zero. If this package is to be delivered on time it will need to be picked up before the package collection vehicle goes to the airport. If delivered on time, this package will be worth $P to the service.

Further assumptions respecting the package delivery service are:

- The package collection vehicle is initially heading towards Airport 1.
- The package collection vehicle requires 5 minutes to reverse its direction.

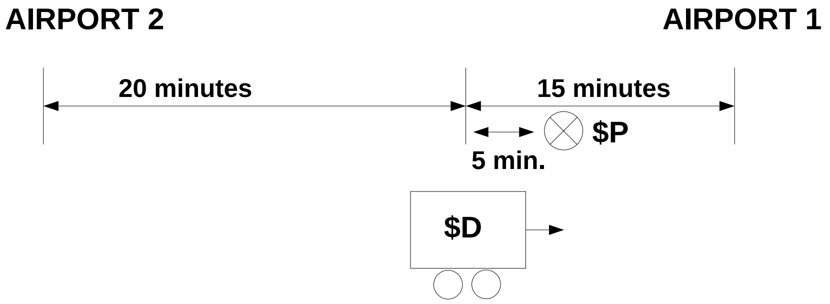
The Time of Receipt (**TOR**) of the **S** and **P** messages has great impact on the value to the package delivery service. The value space is depicted at the bottom of Figure 1. It is not difficult to see that the problem becomes enormously complex with a plurality of packages, reroutes and more complex topologies. Clearly the optimal queueing of messages may have a profound effect on the ultimate value they impart.

## Example 2 — Sensor Fusion

An important problem class is that of effective and iterative sensor fusion under constrained bandwidth communications. To be more specific, let us assume that we have a set of sensors whose outputs are routed through a single point, limited capacity, relay node with queue. The question is, by insinuating just a little intelligence into the node, can it prioritize the messages in a meaningful way?

### Overview

The experiment concerns a missile defense system. We assume that we have S ground based optical sensors that measure the direction cosines of targets as they appear in an area of the sky above them. The sensors are arranged in a circle as depicted in Figure 2. The sensors are able to tie each observation to a particular target and send their observations to a geostationary satellite which relays the observations to a weapons control processing center. The downlink from the satellite is considered to be of limited capacity resulting from link degradation such as jamming or richness of target field.



SCENARIO:
- AIRPORT 1 HAS CLOSED. AIRPORT 2 IS ONLY OPTION.
- THE PLANE FROM AIRPORT 2 LEAVES IN 45 MINUTES.
- A PACKAGE AT ⊗ WITH VALUE $P IS CALLED IN.
- IT TAKES 5 MINUTES TO TURN AROUND.

TWO MESSAGES ARE SENT:
S - INFORMING OF AIRPORT SWITCH
P - INFORMING OF ADDITIONAL PACKAGE

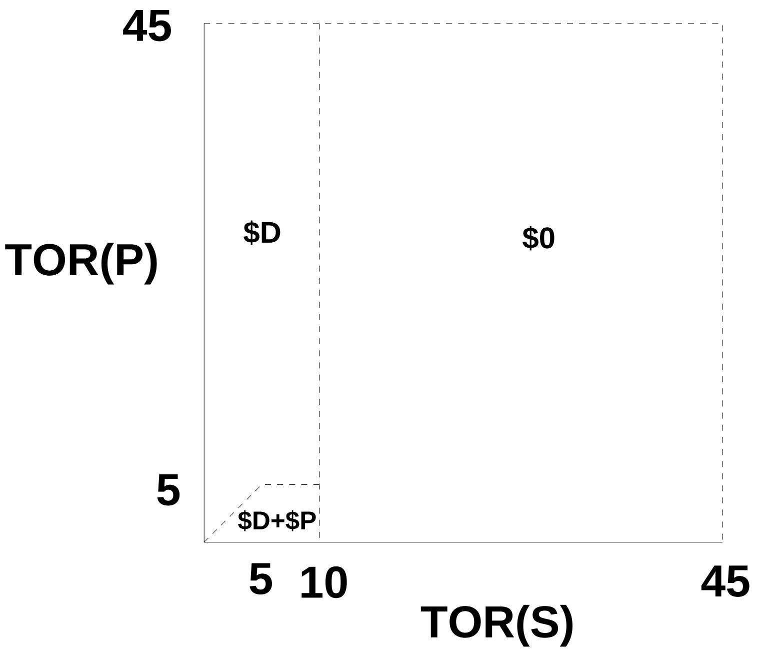


Figure 1 The Package Delivery Service

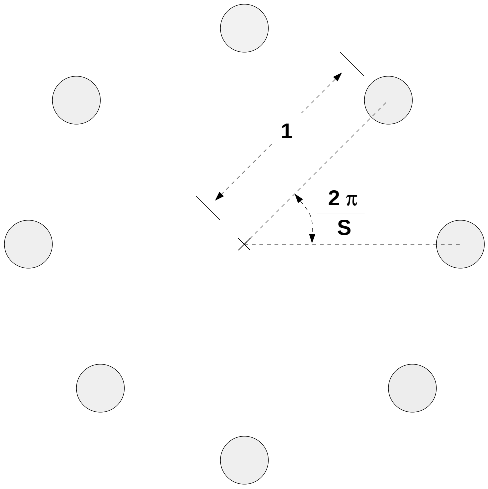


**Figure 2 The Array of Target Angle Measurement Sensors**

The target locations are estimated and a directed energy (DE) weapon is used against them. The probability that the DE weapon will be effective on any particular firing is a strong function of the goodness of the individual target's location estimate. The greater the volume of uncertainty within which the target is to be found, the greater the number of weapon commitments, or, equivalently, DE firings to kill that target. The number of targets in a real situation may be quite large and the number of objects in the target field very large due to shroud components, tank fragmentation and so on. For background see (Reed et al, 1997) and (Mosher, 1997).

The next step is to agree upon a measure of goodness for target location estimation. We desire to be quantitative and as general as possible. For this reason we have selected a *Dilution of Precision (DOP)* metric.

## Geometric Dilution of Precision (GDOP)

The advent of the Global Positioning System (GPS), motivated the necessity to select a calculus for determining what is a *good* selected satellite geometry and what constitutes a *poor* choice. The most popular metric today is a dimensionless single number termed the Geometric Dilution of Precision or GDOP for short. [A review of GDOP bounds and GDOP related material may be found in (Yarlagadda et al, 1997).] The GDOP, in its most general form, comprises an important family of dilution of precision measures. One of these, and the one most relevant to our experiment, is the *Position Dilution of Precision* or (PDOP).

Central to the computation of dilution of precision is a matrix **H**, sometimes referred to as the “visibility matrix,” (McKay and Pachter, 1997), which, for our optical system, is an **n x 3** matrix with $n \geq 3$. The entries in **H** are the direction cosines of the target measured from the individual sensors. Specifically,

$$H = \begin{pmatrix} a_{x,1} & a_{y,1} & a_{z,1} \\ a_{x,2} & a_{y,2} & a_{z,2} \\ \vdots & \vdots & \vdots \\ a_{x,S} & a_{y,S} & a_{z,S} \end{pmatrix}$$

where $(a_{x,i}, a_{y,i}, a_{z,i})$ are the direction cosines of the target measured from sensor **i**. Following (Leva et al, 1996), we can use **H** to find a least squares estimate of the target’s location and we can calculate the goodness of that estimate by computing the PDOP by taking the square root of the trace of $\left(H^T H\right)^{-1}$. **It is important to know that the PDOP will only be reduced by increasing the number of sensors contributing to the estimation of the target’s location.**

## The Experiment

It takes a minimum of three sensors to triangulate a target based on its measured direction cosines. Figures 3 and 4 depict two cases wherein three sensors $S_1, S_2, S_3$ are each reporting the measured direction cosines of the same target in a target field. For the case for Figure 3, the three sensors form a relatively small solid angle with respect to the target and , the error ellipsoid associated with the target location estimate, based on the information from the three sensors, will be elongated and have a relatively large volume. For Figure 4, the three sensors form a relatively large solid angle with respect to the target and the target location estimate is expected to be much better for this geometry. We simulated two cases

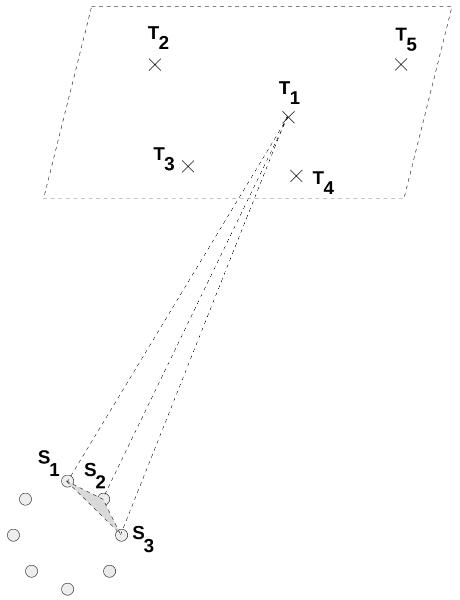


**Figure 3  Three Sensors Providing a Poor Baseline for Target Position Estimation**

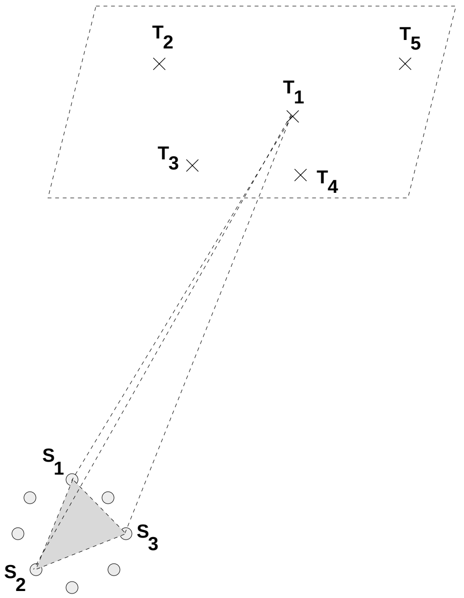


**Figure 4  Three Sensors Providing a Good Baseline for Target Position Estimation**

for which we had $S = 10$ sensors reporting on a target through a single collection point which might be a geostationary satellite which stored the measurements in an on-board queue and then sent the measurements on to a single data sink for further processing such as weapons allocation and battle management. In one case, that of "*No Reprioritization*," the sensors reports were forwarded with no particular ordering. For the other case, "*Reprioritization According to the Simple Heuristic*," we insinuated a degree of ordering, ie, we prioritized the messages according to a simple heuristic in order to improve the PDOP of a particular target **and also to reduce the variation in PDOP** as the target location was sequentially refined. We desired to avoid a computationally intensive effort such as would be involved in calculating $\left(H^T H\right)^{-1}$ and we selected the simple ploy of requiring the *first three* relayed measurements for a particular target to be from sensors that were well distributed around the circle of sensors, ie, three sensors separated from each other by about $120^0$. Note that this is indeed a case wherein a single message has no well defined priority but whose priority is defined in relation to other messages in queue.

## The Results

Figures 5 and 6 depict the results of the experiment. We note that reprioritization based on the simple heuristic makes the PDOP quite good initially and markedly reduces the variation in PDOP as the ten sensor measurements are sequentially fused. As an aside, note that Figure 5 reveals eight different PDOP values with 3 sensors reporting. Figure 7 discloses why this is so. It can be seen from Figure 7 that there are eight baseline classes, A-H, of exactly three reporting sensors, that are inequivalent under rotation and reflection. The baseline 'A' class produces the highest PDOP; the baseline 'H' class the lowest.

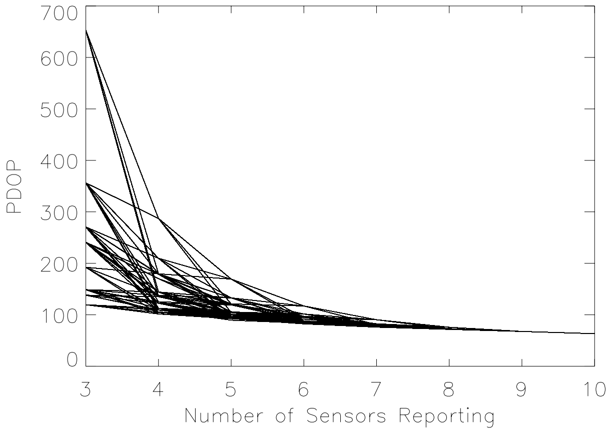


**Figure 5 No Reprioritization**

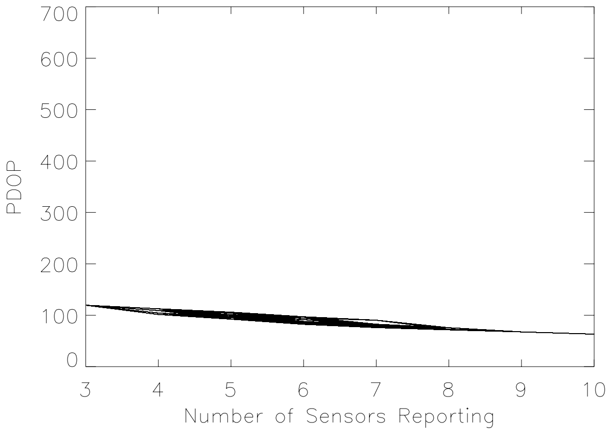


Figure 6 Reprioritization According to the Simple Heuristic

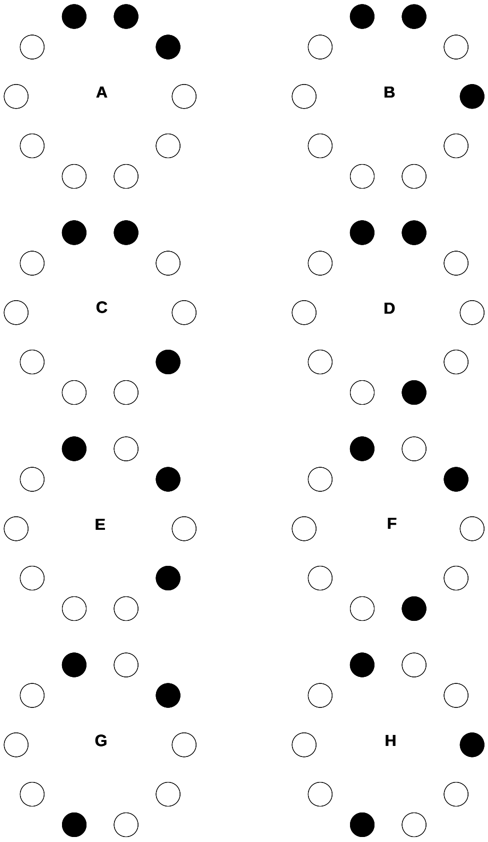


Figure 7 The Eight Three Sensor Baseline Classes for the S=10 Case

## Conclusion

Dynamic reprioritization of a message based on simple heuristics and the knowledge of already sent messages, messages in queue, and, perhaps, messages expected should be a element of consideration for intelligent networks supporting those endeavors that may well expect stressed and degraded communications capacity. Additionally, the use of simple computational heuristics may serve well in effecting admittedly suboptimal but highly efficacious queueing policies. The discipline of active networks is suggested as an appropriate superfield for cabining these activities.

## References

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