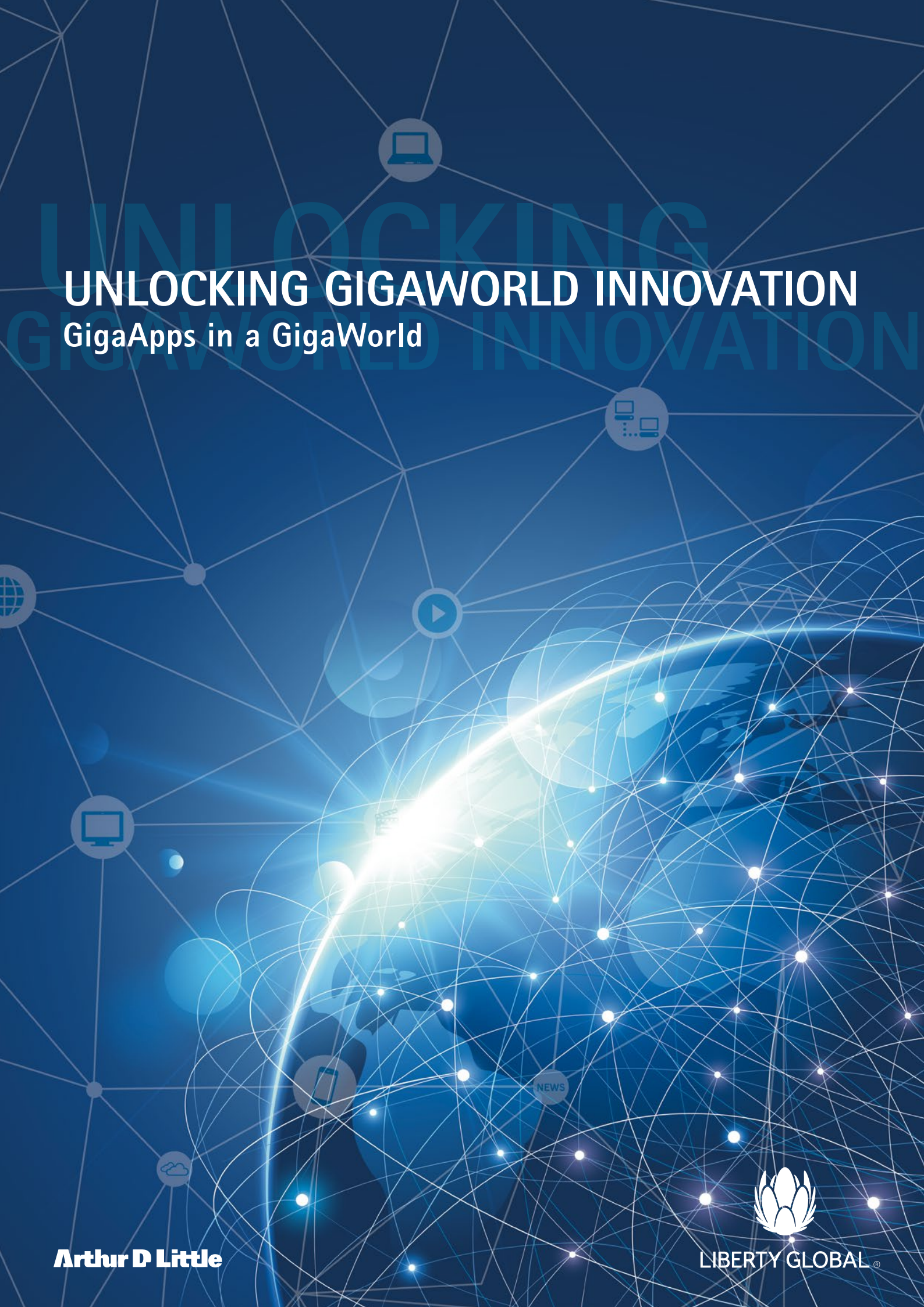
UNLOCKING GIGAWORLD INNOVATION

GigaApps in a GigaWorld



Arthur D Little

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UNLOCKING GIGAWORLD INNOVATION

GigaApps in a GigaWorld

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FOREWORD

SCOPE OF THIS STUDY: "GIGAAPPS AND INNOVATION"

After 30 years of the internet, we are entering a new era. The third industrial revolution leveraged the development of electronics, IT and automated production. The ongoing fourth industrial revolution is driven by cyber-physical systems and fuels a wave of technological innovation that fundamentally alters the nature of digital applications. It is redefining the interactions between people, machines and the environment, and redefining the way we live and work.

A GigaWorld is emerging amidst complex converging ecosystems. This GigaWorld provides solutions to enhance our quality of life, to improve our mobility, to grow our economy and to empower our information sharing and decision-making. With it comes the opportunity to power a virtuous cycle where innovation, investment and monetization work simultaneously to enable massmarket adoption of innovative applications. The dynamics of this virtuous innovation cycle must be well understood to unlock all of its market potential. Networks are central enablers of this fourth industrial revolution and the potential of GigaApplications challenges network operators to raise their game, as they consider the timing of their investments. While some operators are actively investing, a significant number are only partially committed. We are at an inflection point with a huge value at stake. Why are these investments in GigaNetworks so significant, to whom and with what consequences?

This report provides a vision of the GigaWorld. It explains the dynamics of the virtuous innovation cycle and analyzes its core components. It describes three major families of GigaApplications and their potential market value. The report finds that GigaApps require enhanced Quality of Service from networks, bringing opportunities for new monetization models. Network investments must increasingly aim to facilitate a better Quality of Experience and a greater variety of Quality of Service features. In doing so, they will enable the use of GigaApps and unlock billions of new value if market players, policy makers and regulators succeed in driving the next innovation cycle.

Sincerely,

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Executive Summary

EXECUTIVE SUMMARY

The GigaWorld is defining a new internet cycle, with additional network requirements

The second cycle of the internet is reaching maturity. Today's internet – and its enabling applications such as e-mailing, web browsing and video streaming – require asynchronous and/or one-way near real-time data transfer. Wider coverage and greater bandwidth have to date defined its value.

Meanwhile, a GigaWorld is emerging. A world in which people, machines and the environment collaborate intelligently in order to enhance our quality of living, to improve our mobility, grow our economy and empower our information sharing and decision-making.

At the forefront of a new wave of GigaApps, we find Augmented Discovery, Virtual Telepresence and Automated Living. Critical real-time two-way transmission characterizes them. To ensure sufficient Quality of Experience for consumers, the enabling infrastructures and networks must provide new Quality of Service features in addition to coverage and bandwidth. Networks increasingly become the central enabler as they convey the data and interconnect devices and applications.

A new, third internet cycle has started. The success of the GigaWorld will depend on the room its innovation cycle will be given to function, to allow new innovative applications and devices to be developed, networks to be upgraded to GigaNetworks and new monetization models to be adopted.

Figure A

AFTER 30 YEARS OF THE INTERNET, A NEW INTERNET CYCLE IS EMERGING: THE GIGAWORLD

	1st internet cycle (1990 – 2005)	2nd internet cycle (2005 – Now)	3rd internet cycle: GigaWorld (starting now)
Killer Application	• Data Transfer • E-mail • Web browsing	• Uni- & Multicast/ on-demand Video	• Augmented Discovery • Virtual Telepresence • Automated Living
Main Network Requirement	• Asynchronus data transfer	• 1-way "near" real-time • Ubiquitous	• Critical real-time 2-way transmission (latency, security, packet loss, ...)
Monetization – Investment – Pricinig	• Coverage capex • Access & volume-based	• Capacity capex • Bandwidth & volume-based	• Latency & Security capex • Bandwidth and QoE/QoS
"Governing Internet Laws"	• Network-driven	• Bandwidth driven	• Quality of Experience driven
Public Policy – Consumer – Operators	• Everyone connected • Promotion competition	• Best Effort high-speed access • Infrastructure-based vs service-based competition	• Resilience, security and privacy • GigaWorld investment

Source: Arthur D. Little Analysis

The GigaWorld innovation cycle

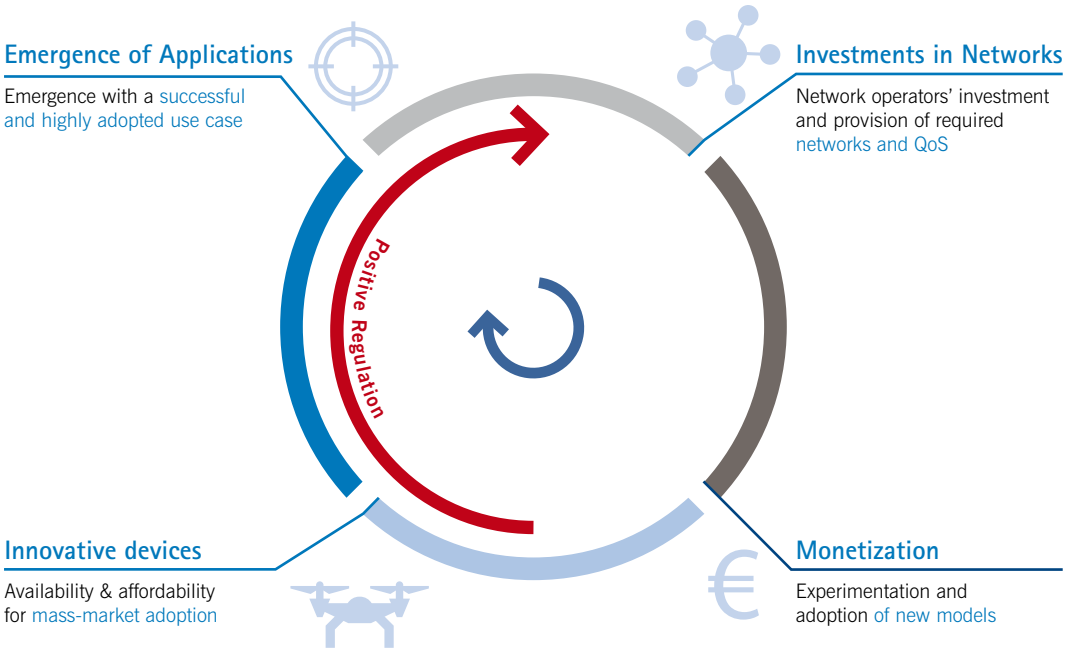
Aligning innovation, investment, monetization and defining effective and enabling public policy is a delicate process of trial and error. The intrinsic value of the GigaWorld innovation cycle comes from its dynamism. With each iteration, the links between innovation, investment and monetization are strengthened, increasing the scope and scale of developing use cases, as innovators and investors strive for mass-market adoption.

All cycle steps (refer to figure B below) and inputs are interlinked, with the weakest link defining the performance of the cycle. Several iterations are generally required before a breakthrough is found, with each iteration bringing greater clarity on consumers' requirements and evolving habits.

Monetization models will go through a continuous process of testing and refinement as players seek to promote uptake and/or simplify usage. New products and offers from initial cycle iterations will largely be limited to early adopters, who test and refine use cases and monetization models. Each cycle iteration triggers a wave of investment improving affordability and accessibility of devices, applications and networks. Uptake of innovative products and services is an iterative and non-linear process.

Figure B

THE GIGAWORLD INNOVATION, INVESTMENT AND MONETIZATION CYCLE



Source: Arthur D. Little Analysis

EXECUTIVE SUMMARY

If we look at the example of healthcare applications, we see that early adopters of the first cycle iterations could be patients whose needs are better served by out-of-hospital monitoring. This can generate better treatment and possible cost savings. Nano-size sensors implanted under the skin and connected to an application that monitors and alerts both patient and doctor in the event of anomalies are an example of a healthcare GigaApp that would substantially improve the quality of life for consumers.

With an increasing number of consumers adopting a successful digital solution like this tele-health monitoring GigaApp, network operators must upgrade their networks to deliver an enhanced Quality of Experience (QoE) for the consumer and therefore upgrade their Quality of Service (QoS) features.

In the short to medium term - 5 to 10 years - we expect the development of three major families of GigaApps with high value creation potential:

- Augmented Discovery: advanced understanding of, and interaction with an environment through a blend of digital content with the physical world, e.g. the broadcasting of holographic sports events or an augmented teaching session.
- Virtual Telepresence: overcoming physical or geographic boundaries or immersive presence in artificial environments, e.g. a seamless retail experience or virtual social interaction.
- Automated Living: delegation of human decision-making and task execution to technology and appliances, e.g. agriculture supervision by drones or patient health tele-monitoring as described in the example above.

The Quality of Experience of GigaApps is heavily dependent on the Quality of Service (QoS) features of the underlying networks, such as high bandwidth, low latency, high reliability, high security, high resilience, widespread coverage, and positional accuracy. With applications becoming increasingly adopted, these QoS features will become the drivers of new monetization models.

We expect that QoS-based monetization models will take various forms according to:

- The intensity of usage: how much is consumed?
- The QoS features requested: which features and how are they provided?
- The underlying service relationship: who pays for what QoS feature?
- The price of the QoS feature.

How the GigaWorld innovation cycle can unlock billions of euros of market value

As Quality of Experience and Quality of Service need to be strengthened, the current internet cycle will no longer provide the context to support the GigaWorld. To be successful, the GigaWorld innovation cycle will require:

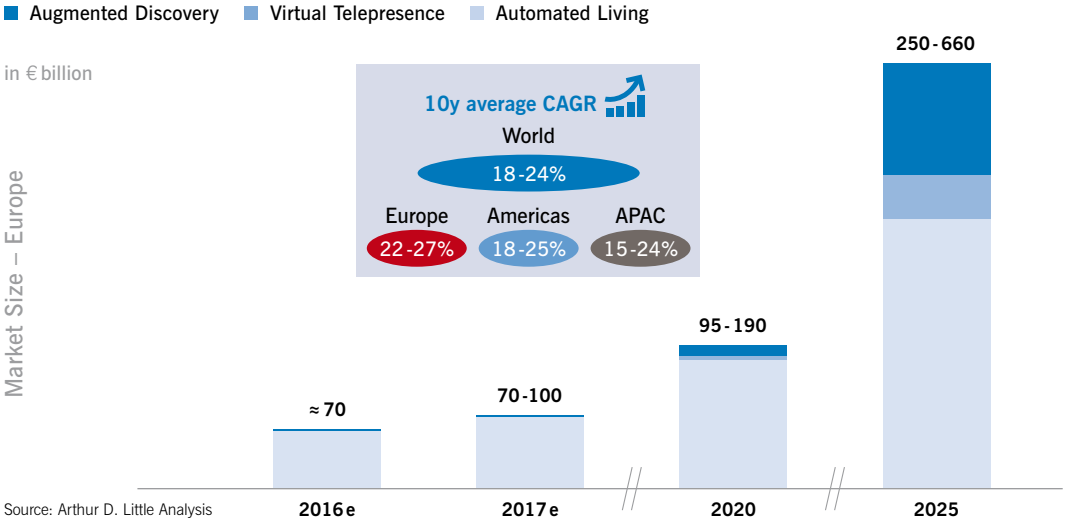
- accelerated digitization, stimulated innovation and uptake, and incentivized network investment,
- predictability and clarity of the public policy framework to stimulate all actors to invest in the GigaWorld and to experiment with new business models,
- a high degree of flexibility and experimentation to allow new monetization models to emerge and the generated value to be distributed between actors and consumers.

With adequate policies[1] accelerating the development of GigaApps, the GigaWorld innovation cycle is forecasted to unlock a market of € 250 - 660 billion per year by 2025 in Europe. At the global level, we are looking at a value of € 1.3 - 3.5 trillion per year (refer to figure C). European GigaWorld markets are expected to grow at an average annual rate (CAGR) of 22 - 27% (18 - 24% at global level). Moreover, every euro invested in GigaNetworks is expected to generate € 2 to € 4 in market value, and around € 4 to € 8 in overall economic value[2].

The inability to efficiently launch the GigaWorld innovation cycle will represent a major opportunity cost in terms of market development of € 150 - 560 billion per year by 2025 in Europe and € 0.7 - 3.1 trillion per year at global level.

Figure C

GIGAWORLD ESTIMATED MARKET – EUROPE



Source: Arthur D. Little Analysis

[1] A holistic, forward-looking and dynamic approach, giving ample room to experiment through trial and error.
[2] ADL research, refer to 6.2

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The GigaWorld vision

1. THE GIGAWORLD VISIO

The Gigaworld: People, machines and environment collaborate intelligently

Year after year, our communication networks expand and operators innovate to manage exponentially exploding data traffic[3]. By 2030, in the vast majority of markets, major GigaNetworks will enable people, machines and environment to collaborate more intelligently. All consumers will have the ability to be connected continuously and exchange relevant information to optimize our individual and collective decision-making. In the GigaWorld, consumers' willingness to share information will grow as immersion into a fully digitized life intensifies. By 2030, the GigaWorld will bring a wealth of added benefits to our daily lives:

- enhancing our **quality of life** e.g. better healthcare, better living conditions at home, better workplaces,
- improving our **mobility** e.g. reduced travel time and a lower environmental footprint,
- growing our **economies** e.g. development of new products and services (e.g. everything-as-a-service platforms) and small and mid-sized companies having access to shared digital capabilities,
- empowering our **information sharing and decision-making** based on billions of new data sources (connected devices), smart data analytics capabilities and trusted encryption.

It is not unthinkable that, around 2030, the number of fatal illnesses may have been reduced substantially. The Pharma industry could be close to delivering on its goal to go from treatment (20th century) to cure (2000 - 2020) to prevention. Health and wellbeing are mainly managed proactively through connected nano devices, and targeted bio drugs are synthesized for individual patients before any symptoms appear. Patient data is accessible everywhere but highly protected thanks to emerging encryption technologies (e.g. blockchain).

Non-motorized transport[4], public transport and shared on-demand transport in 2030 represent the majority of traffic and eventually start to solve the mobility issues of large urban areas. Autonomous vehicles represent more than 30% of traffic, and Integrated Transport Systems boost the capacity of mobility networks thanks to instantaneous optimization of traffic flows. Mobility has become cleaner and is fully integrated with electric networks providing a multitude of stations for charging and exchange of batteries.

Unmanned vehicles (i.e. drones) are extensively used for transportation of goods and redefine logistics as shops become virtual and consumers do not need to carry their purchases anymore.

[3] Global IP traffic as well as Mobile data traffic are expected to increase nearly threefold by 2021. Global IP traffic increased by ~30-fold since 10 years (source: Cisco)
[4] Charter of Brussels, signed by 60+ cities in Europe, sets at 15% bicycle modal share by 2020

In factories, many tasks are almost fully automated and out-of-factory equipment is permanently monitored. People have continuous access to supportive information to perform their tasks. For example, field technicians have access to data from the cloud, displayed via augmented reality. Artificial intelligence is also used to anticipate the situation and proactively provide the most relevant data to each technician. Better integration of customers and suppliers via connected data is substantially reducing waste. Drone-robots are sent to remote locations while qualified technicians and engineers remotely steer them to perform basic or complex tasks of maintenance, deployment or installation. Designers and product developers meet in virtual holographic working places and exchange on 3D prototypes in a simulated real-life environment.

Energy management in 2030 has little in common with early 21st century practice. Decentralized and clean energy production units have become the norm; everyone is both a consumer and a producer. Smart power grids manage billions of connected devices and appliances to optimize energy production and consumption. The reach of fully electric devices, vehicles and mobile appliances has been extended thanks to breakthroughs in battery storage and a wide range of systems that optimize battery management.

In this world - the GigaWorld - GigaNetworks empower people by giving them the freedom to connect, exchange, compare, work and improve their quality of life.

Industries converge into complex ecosystems

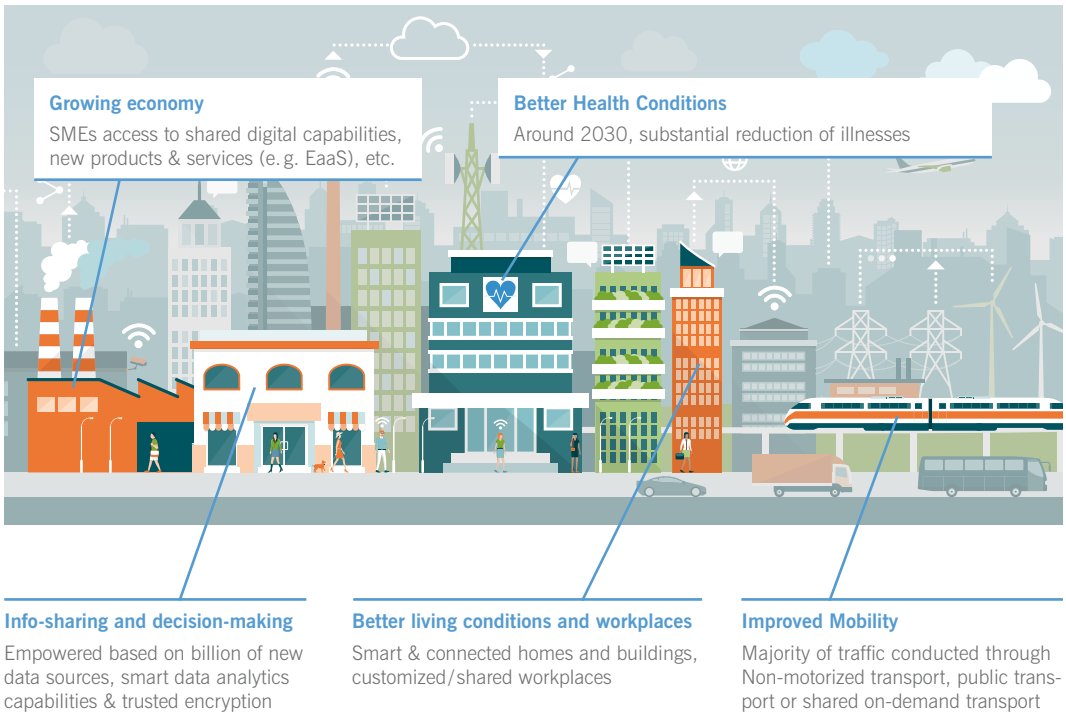
Ubiquitous connectivity and advances in digitization will drive the development of new use cases and services and bring fundamental change to industries.

- sensors and connected devices translate the physical world into data flows almost instantaneously for all industries, increasing the scope and pace of interactions between industrial activities previously developed in silos,
- new data is accessible and shared across industries, opening opportunities for actors to become relevant and enter into an adjacent industry,
- customer interactions are enabled by digital devices and applications, providing commonalities for industries to compete and/or collaborate.

1. THE GIGAWORLD VISION

Figure 1

GIGAWORLD VISION



Source: Arthur D. Little Analysis

Therefore, ecosystems formed by industrial and technological players become more complex. More collaboration between actors shapes new innovative digital solutions for traditional sectors. Networks increasingly become the central enabler as they convey the data and interconnect devices and applications.

"Ecosystems created by converging industries are shaping innovative digital solutions for traditional sectors."

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The GigaWorld and its innovation cycle

2. THE GIGAWORLD AND ITS INN

2.1. The GigaWorld is emerging

1st internet cycle: connecting everyone

In the 1990s, adoption and usage of the internet by consumers and businesses accelerated substantially. Usage and traffic were driven largely by e-mailing, data transfer and web-browsing services. These applications required networks to be able to deliver asynchronous data transfer. Data was delivered from point A to point B and small delays would either go unnoticed or be acceptable.

Network usage drove the value of the internet: the more people connected, the higher the value to all internet users[5]. Hence, network investments were designed to increase the coverage of people connected to the internet, which in turn increased the value of the internet. Consumers would pay the right to access the network (monthly subscription) and, in the main, use it on a perminute basis (dial-up pricing plans).

Public policy intervention was designed to ensure connectivity services were deployed as widely as possible, whilst introducing service competition to incumbent telecommunication monopolies.

Figure 2

AFTER 30 YEARS OF THE INTERNET, A NEW INTERNET CYCLE IS EMERGING: THE GIGAWORLD

	1st internet cycle (1990 – 2005) AOL, Gmail, Wikipedia	2nd internet cycle (2005 – Now) NETFLIX, YouTube, facebook	3rd internet cycle: GigaWorld (starting now)
Killer Application	• Data Transfer • E-mail • Web browsing	• Uni- & Multicast/ on-demand Video	• Augmented Discovery • Virtual Telepresence • Automated Living
Main Network Requirement	• Asynchronus data transfer	• 1-way "near" real-time • Ubiquitous	• Critical real-time 2-way transmission (latency, security, packet loss, …)
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"Governing Internet Laws"	• Network-driven	• Bandwidth driven	• Quality of Experience driven
Public Policy – Consumer – Operators	• Everyone connected • Promotion competition	• Best Effort high-speed access • Infrastructure-based vs. service-based competition	• Resilience, security and privacy • GigaWorld investment

Source: Arthur D. Little Analysis

[5] Metcalfe's law describes how the value of networks is proportional to the square of the number of connected users of the system

2nd internet cycle: all about increasing capacity

At the start of the new millennium, a new generation of innovative devices (tablets, smartphones) and applications (IP video streaming techniques) emerged. Video streaming services were rapidly adopted whether on-demand or "live". These new devices and applications enabled uni-/multicast video streaming and on-demand video streaming or downloading. With large amounts of data being streamed or downloaded for immediate consumption, network investments focused on adding capacity (bandwidth). Bandwidth evolution followed Nielsen's law: internet speeds doubled every 18 months. Progressively, as mobile networks increased their capacity, consumers started to consume video on-the-go and ubiquity of access became a requirement.

Monetization models changed as users were willing to pay more for bandwidth capacity. Still the change was limited because the existing volume-based models were simple, therefore attractive, and mobile bandwidth was difficult to guarantee.

However, these adapted models did not capture the growing demand for delivering data in "near real-time". Delays in data transfer, or latency, needed to be addressed to avoid buffering or image degradation. Compression techniques and Content or Application Delivery Networks[6] provided technological solutions for one-way video streams. New business models emerged and monetized the video compression advances: these business models distributed the value generated in the chain and had limited impact on consumers.

A new internet cycle: The GigaWorld

Today, companies around the world are investing billions to develop GigaApps that will enable the integrated, fluid living of the GigaWorld. New GigaApps will emerge, clustered around three main families of applications:

- **Augmented Discovery:** data provision and search in real-time via augmented reality technology, often location-based,
- **Virtual Telepresence:** real-time virtual holographic representation of people, their context and - often - their environment,
- **Automated Living:** remotely accessing and controlling Things, and Things interacting with other Things autonomously.

These GigaApps share the need for new network performance criteria. They are defined by their requirement for real-time two-way data transmissions of high-quality video and high-quality critical and secured data streams. Consumers of the GigaApps of tomorrow will demand enhanced Quality of Experience (QoE). In turn, this will require major network upgrades and additional network investments to enable the necessary Quality of Service (QoS) features such as low and consistent latency, high reliability, security and high resilience (see chapter 4).

In this new environment, GigaNetworks will create value by providing these QoE features, and over time, monetization models will reflect the incremental value unlocked by the provision of higher and on-demand QoE characteristics.

[6] CDN/ADN. For more detail on such technologies and business models, please refer to our „The Future of the Internet" report (www.adl.com/FutureOfTheInternet)

Public Policy intervention will need to shift towards accelerating the widespread deployment of these GigaNetworks through investment-incentive based regulation, whilst improving resilience, security and privacy for consumers.

A new internet cycle, the GigaWorld innovation cycle, we predict, will emerge around 2020. Its success will depend on the ability to digitize new innovations, the emergence of GigaApps, on the pace of deployment of GigaNetworks and on the adoption of new monetization models.

"A third internet cycle, the GigaWorld, is emerging adding new network requirements building on those of 1st and 2nd internet cycles."

2.2. Innovation in the GigaWorld is powered by a virtuous cycle

Aligning innovation, investment, monetization and the role of public policy is a delicate process of trial and error, as illustrated by the tension that arose during the emergence of the 2nd internet cycle. The GigaWorld innovation cycle could be launched more smoothly by anticipating discussions and collaboration between the key stakeholders. To understand how this process can be optimized, we examine three use cases.

» Mobile TV services
» Over-the-top-video services and
» Mobile healthcare services.

The failure of Mobile TV

The first wave of Mobile TV services failed to achieve mass-market adoption. They were eventually abandoned as innovation, investment, business models and policies failed to align in an effective innovation cycle.

These initial applications tried to replicate the traditional TV broadcasting model. Mobile devices required the addition of broadcast spectrum receivers. Mobile TV was predetermined to be a killer app before use cases proved themselves. Image quality and battery performance were sub-optimal whilst consumer propositions were unappealing with poorly designed business models that consumers were unwilling to adopt; e.g. there was no subsidization of handsets to accelerate adoption.

Public policy intervention was also misguided in its attempt to enforce the DVB-H technology

as the single operating standard, despite several operating limitations (lack of available spectrum) for operators.

Limited take up of the first wave of use cases as well as technology and license restrictions discouraged pioneering device manufacturers such as Nokia, Samsung and Apple to invest in the broader development of Mobile TV enabling devices. Similarly, investments in DVB-H networks were delayed or cancelled in most markets resulting in the shut down of the DVB-H Mobile TV initiative by 2012.

This shows that a prescriptive approach towards consumers and technology providers lacked the flexibility required to endorse and promote disruptive innovations.

"You cannot prescribe technology disruption."

The emergence of OTT VoD

The emergence and widespread adoption of Over-The-Top Video-on-Demand (OTT VoD), is by contrast, an example of how the innovation cycle can work successfully.

To meet consumers' desire for tailored content offerings over any device, anytime, anywhere, a range of OTT VoD offerings have been developed, tried and tested. Initially, web browserbased video streaming services like YouTube and Dailymotion met consumers' needs. They quickly reached mass-market adoption, largely monetizing their platforms through advertising.

To improve delivery quality, further investment to optimize the video streaming experience was needed. New compression protocols and higher bandwidth were required, neither of which were supported by initial business models.

As tablets and connected TVs became mainstream, consumers' desire for seamless viewing across devices grew. Equally, the DVD rental model was displaced by digitized content offerings from a new wave of online platforms for a better price and with an enhanced experience. Today, a wide range of video streaming devices is available at a variety of price points, enabling mass-market adoption.

With Video being increasingly the main source of traffic on networks[7], network operators continuously invested in higher bandwidth and Content Delivery Networks. As the video viewing Quality of Experience improved, OTT video service providers started to invest in higher quality content. The result was an adoption of a new wave of binge viewing, anywhere, anytime offerings.

Widespread adoption of OTT video streaming resulted in new monetization models including flat-fee monthly video subscription and advertising-based video subscription models. Although debates between network operators and OTT service providers on how to share the newly created value have been lively, involved stakeholders reached consensus over the new equilibrium and value distribution.

This case demonstrates how experimentation and several iterations of the innovation cycle led to a new equilibrium and a new distribution of value between stakeholders, resulting in mass adoption of OTT video by consumers.

[7] Cisco: 70% of all consumer internet traffic in 2015

Emergence of GigaWorld healthcare apps

To meet the challenge of affordable healthcare services for a growing and ageing population, a huge wave of investment and innovation into mobile care services and telemedicine applications has started.

Healthcare services - from diagnosis to treatment - are increasingly moving beyond the hospital. Tomorrow's healthcare services will be a world of tele-monitoring and selfcare, robot-assisted remote tele-surgery, and telemedicine diagnosis, all remotely supported by healthcare professionals and enabled by GigaWorld connectivity.

To deliver these services and monetize their costs, the innovation cycle must allow for a period of experimentation in technologies, use cases and funding models.

Patients and healthcare professionals must be encouraged to trial new digital solutions, e.g. wearable systems for monitoring, diagnosis and treatment of chronic diseases. Network operators will need to ensure their infrastructure is fit-for-purpose. Improving latency response times and providing higher bandwidth are critical to providing reliable real-time connections between patients and healthcare professionals, as well as for consultation video streams. Equally high levels of resilience and security are critical to create the necessary confidence level, e.g. to allow the sharing of rich patient data sets.

A variety of business models will be tested as these services will become more common. Public health authorities may choose to extend purchasing subsidies to applications or new e-health devices; private healthcare providers may require patients to contribute partially to the costs of devices, applications and the connectivity, or possibly, also for the supporting healthcare professional.

The success of new health apps will encourage further investment in devices and, as new services reach mass-market adoption, network investments will be made on the assumption that emerging business models recognize the benefit of additional high quality network features, whether paid directly by the consumer or indirectly by other ecosystem stakeholders.

The number of GigaWorld e-health applications per patient will increase substantially as more innovative monitoring and intervention devices and solutions will be used; e.g. remotely controlled injections and video assisted medical consultations. As a result, business models will start to overlap and the complexity of the e-health ecosystem will increase. This may well lead to some players taking the role of ecosystem service provider, aggregating the various business models and offering a simplified service to customers.

The success of GigaWorld healthcare applications depends on the ability of device manufacturers, e-health application providers, network operators, consumers and key stakeholders like insurers, to test use cases, build trust in their monetization potential and continuously adapt and improve their respective contribution.

The virtuous innovation cycle: dynamics & key success factors

In order for game-changing GigaApplications to develop, the innovation cycle of the GigaWorld must be optimized. Innovation, investment and monetization models are intrinsically linked and must work simultaneously for a virtuous innovation cycle to emerge and function. In the GigaWorld, such a cycle functions as follows (the starting step is irrelevant):

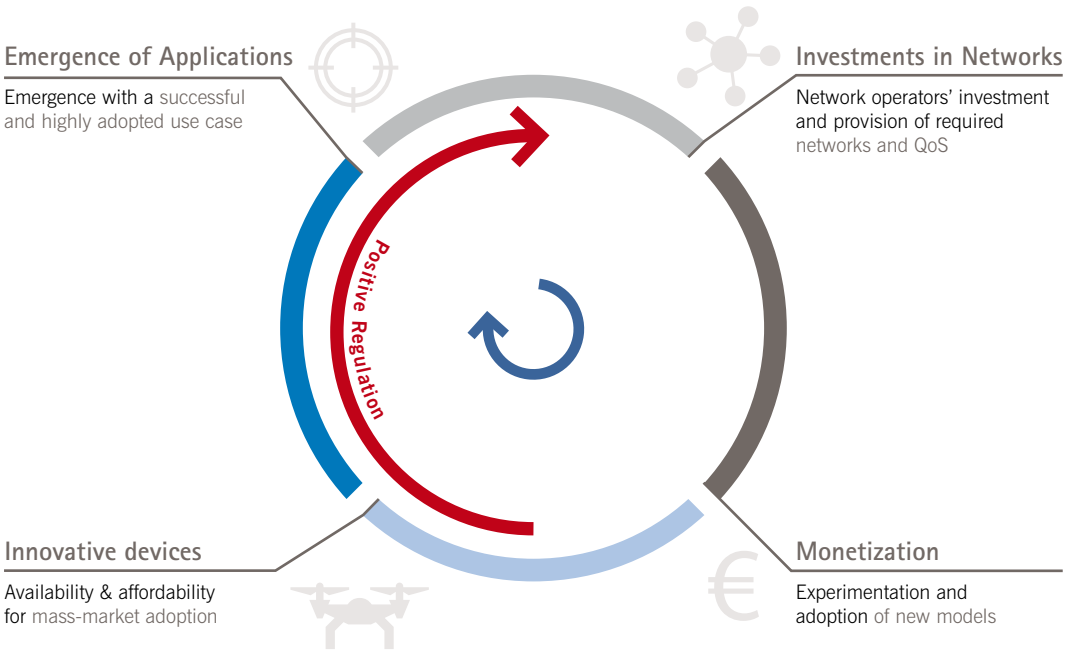
» New technologies emerge from the innovation ecosystem, are tested in lab conditions, before a small proportion become available and affordable as consumer devices.

» Some of these technologies and/or devices have the potential to enable GigaWorld digital applications, of which a limited number will enjoy widespread adoption by virtue of their userfriendliness and the attractiveness of their use-case. Mass adoption of such "killer apps" will lead to market disruption and fundamental changes in behaviour and processes.

» Network operators anticipate new network requirements to support the Quality of Experience (QoE) required by emerging GigaApps. Next to additional capacity, other Quality of Service (QoS) features are increasingly becoming critical and drive investments in GigaNetworks[8].

Figure 3

THE GIGAWORLD INNOVATION, INVESTMENT AND MONETIZATION CYCLE



Source: Arthur D. Little Analysis

[8] e.g. Fiber-to-the-home, DOCSIS 3.1, 5G

» As use cases are adopted at scale, application providers and network operators develop new monetization models. Recognition by consumers of the value of additional capacity and enhanced Quality of Experience will contribute to further financing of network investment.

The value of the GigaWorld innovation cycle comes from its dynamic nature. With each iteration, the link between innovation, investment and monetization is strengthened. In turn, the range and scope of use cases and market players' increases, and more innovative apps become mass-market.

The virtuous cycle is characterized by the following:

» **The weakest link defines the cycle's performance:** As all inputs and processes are interlinked, the weakest link defines the success of a cycle iteration. If new technology breakthroughs are not effectively translated into applications that address a relevant use case, massmarket adoption will not take place and network investment will be curtailed. If networks are not able to deliver the required Quality of Experience, customers will not adopt the applications, thereby discouraging further innovation. If monetization models are too complex, network investment and innovation will be discouraged or delayed.

» **Several iterations are required before a breakthrough is achieved:** each iteration tests key features of a consumer use case. Successful mass-market adoption of an application will only take place through a process of experimentation and trial and error.

» **Monetization models require continuous testing and shaping:** As consumer test the new waves of GigaApps, they are likely to adopt several applications simultaneously. Over time, overlapping use cases are replaced as providers refine their offerings. In turn, consumers understand better which propositions they really value and are willing to pay for. In response, application service providers, device manufacturers and network operators compete to offer the most attractive monetization model.

» **The timing of widespread adoption will not be uniform:** The first uses cases will largely be adopted by specialized groups who can afford initial high costs of innovation and network deployment. These early adopters test and shape initial use cases and monetization models. Over time, additional ecosystem players invest, thereby improving both the affordability and accessibility of devices, and GigaApps.

» **New internet cycles are built on the output of earlier cycle iterations.** For example, GigaApps will develop on top of existing 1st and 2nd internet cycle data transfer and video application improvements. Similarly, Quality of Experience features of GigaNetworks will be added on top of earlier investments in coverage and bandwidth.

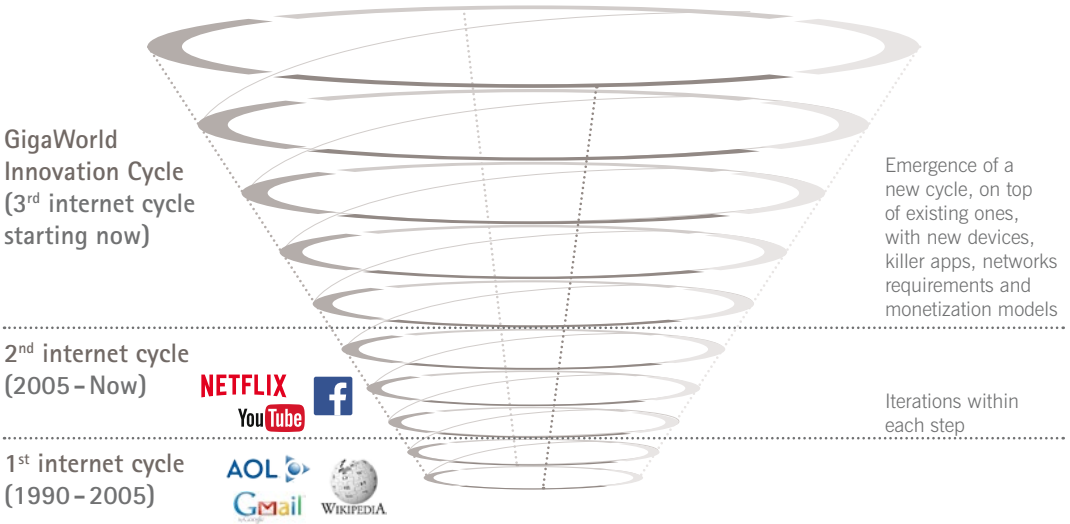
» **Policy and regulation have a key role to play in the functioning of the virtuous innovation cycle:** it is essential that investment and innovation by all ecosystem players is stimulated. Equally, the policy and regulatory environment must enable greater collaboration between players to accelerate the cycle iteration, through a flexible light touch approach.

The evolution of today's innovation cycle to a new virtuous GigaWorld model is a major undertaking. It requires commitment from all ecosystem players if the true potential of the GigaWorld is to be unlocked. Equally, it requires adaptation to new forms of collaboration between vertical industries, public bodies, technology companies and their investors.

The next four chapters will each focus on one key step of the GigaWorld innovation cycle: the nature of GigaApps (chapter 3), the translation of Quality of Experience into new network requirements (chapter 4), the necessity for new monetization models that capture the value generated by the network investments (chapter 5) and the GigaWorld market potentials (chapter 6).

Figure 4

ITERATIVE DYNAMIC AND CUMULATIVE DYNAMIC OF INTERNET INNOVATION CYCLES



Source: Arthur D. Little Analysis

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A world of emerging GigaApps

3. A WORLD OF EMERGING GIGA

The GigaWorld is characterized by a new and more intense innovation and investment cycle that is capable of unleashing a range of new technologies with the potential to enable disruptive digital applications.

Exponential growth in computing power will enable technological breakthroughs on multiple fronts. IoT, autonomous vehicles and robots, VR/AR, automated living and augmented discovery will fundamentally change our world, making life in the GigaWorld an exciting reality.

While some of these new technologies - such as brain-computer interfaces, quantum computing, artificial intelligence, machine learning - are unlikely to reach mass market adoption soon, a myriad of new technologies will become the main drivers for the GigaWorld of digital applications.

These apps, and the networks enabling the required Quality of Experience, will deliver benefits to many European consumers and enterprises.

We anticipate that three major families of applications have the potential to generate substantial new value creation in the GigaWorld:

» Augmented Discovery,
» Virtual Telepresence, and
» Automated Living.

Each of the families will be supported by emerging technologies such as:

» Augmented Reality (AR) - visual reality enhanced by superimposing images or data
» Virtual Reality (VR) - the experience of being totally immersed in a purely virtual world
» Advanced data analytics, creating new ways of monetization and consumer service insights
» Advanced Robotics: enabling devices to perform advanced tasks with physical impact

GigaApps supported by these technologies will profoundly transform most sectors of our economy: from traditional industrial sectors such as manufacturing and automotive, to sectors such as healthcare, entertainment and retail. Unlocked value creation from this new wave of GigaApps is forecasted to reach € 250 to 660 billion per year by 2025 in Europe alone[9].

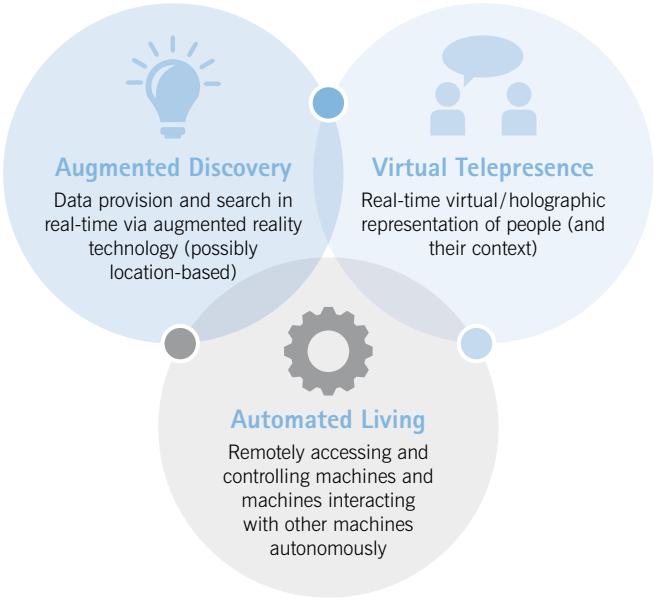
Augmented Discovery

Augmented Discovery allows an advanced understanding of our environment through a blend of digital content with the physical world. Consumers are empowered with new tools to understand their environments using superimposed digital imagery on top of a physical location, device or interface (e.g. using a Google glass or a Microsoft HoloLens device). Projected information could be in the form of words, arrows or other signs, created real-time by computer graphics that are added by the device to the physical environment where the user is present. By 2025, Augmented Discovery is expected to constitute a market estimated at € 80 - 175 billion per year in Europe[10].

[9] ADL research, refer to chapter 6.2
[10] ADL research, refer to chapter 6.2

MAIN FAMILIES OF GIGAAPPS

Figure 5



Source: Arthur D. Little Analysis

Already now, Augmented Discovery services are developing rapidly in light of technological advancement of AR devices such as:

- Simultaneous Localization and Mapping (SLAM) - to register consumer movement
- Depth-sensing cameras - to capture 3D videos and
- Pico projectors - to project images and data

Augmented Discovery applications have a range of benefits:

- **Visualization of and interaction with the external environment.** For instance, technicians equipped with AR devices working on a complex maintenance task will be aided by visual instructions and rendered images in real time.
- **Reconstruction of an environment enriched with information related to the reconstructed object, event and/or action.** For example, 3D holographic projection of sport, musical or political events augmented by layers of superimposed information regarding the event (see box).

HOLOGRAPHIC SPORT EVENT BROADCASTING

BACKGROUND

Spectators of major sports events often have limited visibility of the entire event. Conversely, viewers at home are often restricted in how they can view the event by broadcasters editorial or scheduling decisions.

SOLUTION

Emerging video applications aim to narrow the gap between the real-world and the remote experience. They give the audience an enriched live experience by enabling them to follow a digital replica and give them control of what they follow. Combining 3D sound, 3D hologram reconstructions, live projections, and even replica stadium seating, spectators are able to interact with the projections and request aditional information.

FUTURE

Development of these application is already underway. Devices such as Microsoft Hololens and Google Glass allow visualization of holograms with a high degree of realism. 3D sound systems like 3D Sound Labs's smart headphones bring a higher level of aural immersion. Experimentation in broad-casting live events in holographic form has already taken place. Further holographic projections are being piloted e.g. Microsoft HoloLens's sports events projection and Mitsubishi Electric's 3D hologram for the Tokyo Olympics 2020.

Source: Microsoft Hololens

Other Augmented Discovery use cases include:

» **City discovery guides:** augmented reality individually tailored information is projected on an AR device providing tourists with an enriched discovery environment.

» **Smart Shopping:** shoppers are assisted via AR in their search for items or services. Artificial Intelligence identifies and filters items viewed according to consumer's preferences and habits.

Virtual Telepresence

Enabled by advanced robotics, holographic projections and VR devices, this family of applications effectively overcomes geographic boundaries by immersing consumers in a virtual world in which holographic representation of people and their environment is provided real-time. By 2025, Virtual Telepresence will reach a market of € 20-60 billion per year in Europe[11].

[11] ADL research, refer to chapter 6.2

Virtual Telepresence benefits include:

» **The perception of being physically present in a non-physical world**, and of being immersed in a virtual space. For example, in Virtual Social Networks, consumers are immersed in artificial environments where they interact with friends and with connections, with the ability to express emotions and share memories in real time.

» **The experience of being physically present in a place other than one's own location and additionally having the ability to manipulate the other place's environment.** For instance, robot-assisted remote surgery allows a doctor to perform surgery using robotic arms on a patient not physically present in the same location.

SEAMLESS RETAIL EXPERIENCE: SMART SHOPPING

BACKGROUND

Shopping in person is a time-consuming experience. Online shopping emerged as a time- and mobility-convenient solution but it lacks the entertainment value and personal advice.

SOLUTION

In the retail experience of the future, a shopper:

» will be immersed in a virtual store – an actual copy or a visualisation of a physical retail location

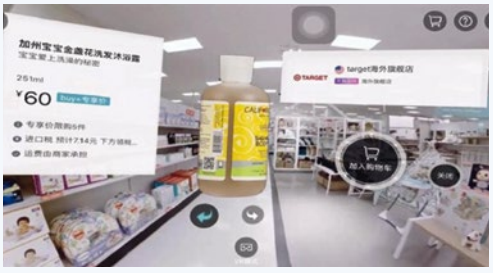
» can freely walk around and pick any item while being assisted by a virtual sales agent

» can seamlessly pay and have their purchases delivered to their home

During this immersive experience, items can be tested in the virtual environment, e.g. in a virtual fitting room.

FUTURE

Smart shopping requires VR head-mounted-devices (HMD) such as Facebook Oculus or Samsung Gear VR. Moreover, advancements in artifical intelligence enable a virtual assistance experience that includes both interaction and information exchange. Such a retail experience was launched by Alibaba in Q4 2016: the Buy+ virtual store.



Source: Buy+ by Alibaba, Inteli Group Virtual fitting room

Other Virtual Telepresence use cases include:

» **Collaborative Telepresence** via Hologram - meeting participants communicate via holograms projected into each others' physical location.
» **Virtual real-estate sales** - enabling realtime remote viewing of properties.
» **Virtual reality (educational) gaming** - large organizations increasingly use game playing scenarios as a method of corporate training and employee communication.

Automated Living

Automated Living applications delegate, either partially or fully, human decision making. This enables routine tasks to be initiated or undertaken by machines. By 2025, the Automated Living market in Europe is estimated to reach € 150 - 425 billion of revenues per year[12].

Automated Living applications rely on the expansion of connected devices, big data analytics and machine-to-machine communication.

Its benefits include:

» **Autonomous task execution:** For example, autonomous robots performing home-cleaning activities, a drone-robot performing basic maintenance tasks such as street light bulb replacement or cleaning and maintenance of skyscraper windows.
» **Advanced data analytics:** Integrated data from various sources (devices, structured and unstructured databases) is being used to execute statistical analysis and data modelling, and machines will learn to adapt themselves to new analysis requirements. For example, building management systems will provide analysis of probable breakdowns, and adapt servicing schedules through machine learning protocols.

[12] ADL research, refer to chapter 6.2

ADVANCED SMART CITIES – A CASE STUDY OF AUTOMATED LIVING IN PRACTICE

BACKGROUND

Major cities are shaping their environments to be future "smart cities". New urban surroundings with enchanced data capacity resources and millions of simultaneously connected "Internet of Things" (IoT) sensors are developing. GigaWorld networks provide the connectivity underpinning these smart cities, monitoring and controlling the intelligent city infrastructure.

Citizens enjoy enhancements to their quality of life and cities drive efficiencies in public administration and services, increasing productivity and enabling more sustainable consumption patterns. Smart cities are expected to contribute up to a GDP increase of approximately 15% (source: ADL research, Cisco).

SOLUTION

Many cities are developing Smart City roadmaps to build the sensors, devices, and intelligent infrastructure that enable a range of smart city applications.

Some of these technologies, such as street parking sensors, CCTV cameras and automatic gates are already widely deployed. Other elements, such as energy storage devices and intelligent traffic management systems remain to be deployed. Data gathered from these devices are generally centralized in Smart City platforms that constantly monitor and assess the efficiency of a city's services and infrastructure.

FUTURE

Several large cities like Nanjing, Vienna, Dubai, and Espoo are starting to deploy smart city infrastructures.

Smart City platforms of the future will enable autonomous management of many aspects of city life, from automated updates of Intelligent Traffic Systems to optimising solutions for emergency service communications and enhancing connectivity for industrial regeneration zones.

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Enhanced networks are required to build the GigaWorld

4. ENHANCED NETWORKS ARE REQUIRED TO BUILD THE GIGAWORLD

4.1. GigaApps will broaden the concept of Quality of Experience

The pace at which a new wave of GigaApps will be brought to market will, to a large extent, be determined by the Quality of Experience features of GigaNetworks. Their resilience, reliability, immediacy and ability to "specialize" render them an essential element in the success of GigaApps. If the QoE standards are not met, consumers will not adopt a new application, nor will they be prepared to pay for them.

Today QoE is mainly defined by the speed at which data is available, for instance a large data transfer from/to the cloud or video download, and the perception of instantaneity for one-way video streams, i.e. no buffering or downgrading to low definition. However, widespread adoption of the GigaApps of tomorrow will demand the expansion to a range of new QoE features that GigaNetworks must offer.

Take the case of a small agriculture enterprise equipped with several drones. They supervise estate management, autonomously sow seeds and continuously analyze the date on which harvesting should take place. The farming business will expect uniform and seamless performance across the entire estate, continuity of service delivery (e.g. sensors for parasite or illness detection) and accuracy of analysis.

Consider now a transport company investing in a connected and self-driving vehicle service. It will require networks, which are secure from electronic hacking, with low latency to ensure effective and flawless communication with other vehicles and roadside infrastructure such as traffic lights, whilst gathering real-time environment and traffic information that will influence route, braking or speed.

Or imagine a qualified engineer following a remote training session on a new industrial technology via holographic telepresence. He will expect a video flow with a high level of realism, instantaneity and a resolution akin to being on site with the trainer.

Each of these GigaWorld use cases and their Quality of Experience call for specialized network performance and features in particular:

- **The perception of reality** from high quality, high definition audio-visual data streams; giving the illusion of real sight, hearing and interaction.
- **The perception of instantaneity** in interactions with the virtual surroundings.
- **Assurance of accuracy** of data collected and commands executed.
- **Assurance of security** preventing unauthorized access to data or devices.
- **Assurance of service continuity**; i.e. no unforeseen interruptions.
- **Ubiquity**; i.e. a uniform and seamless experience in all locations whatever the device.
- **Flexibility**; i.e. being able to cater for special features when and where wanted.

4.2. Alongside bandwidth bandwidth, GigaNetworks must provide essential Quality of Service features

The ability to provide this specialized Quality of Experience is dependent on a number of factors: the device, the application and user interface, the service provider and - critically - the features and upgrades deployed in the underlying networks.

Although plans to introduce these additional performance criteria exist, network operators have yet to undertake widespread implementation. Greater emphasis on and investment in these features is necessary if the GigaWorld vision is to be realized.

For sure more bandwidth ...

What remains beyond doubt is that the demand for more bandwidth will continue to increase, although there are variations in the estimates of demand[13]. Cisco[14] foresees substantial growth of global IP traffic over 2015 - 2020, with the peak-hour traffic increasing by 32% annually, while global IP video traffic is expected to grow by 31%. Connected things are expected to reach € 50 billion by 2020 with their traffic growing by 44% per year. Cloud-enabled services and intense video services (with migration to 4K and 8K) will continue to be primary drivers. Moreover, Augmented Discovery, Virtual Telepresence and Automated Living will require top-notch resolution and large amounts of data to be downloaded/uploaded from the cloud to process contextualized data.

... but also more Quality of Service features

Nevertheless, adding more capacity alone will not address the need for improved Quality of Experience features. Low latency, improved reliability (packet loss and low jitter), enhanced security and resilience are essential upgrades to the capabilities of today's Giga Networks. The Quality of Service (QoS) demands require the following improvements to networks:

- **Low and consistent latency** to reduce the delay in data communications. This QoS is required for real-time instantaneous data transmissions. Take, for example, critical machine-to-machine communications such as connected vehicles safety systems or live two-way video streams such as holographic telepresence.
- **High reliability (packet loss and jitter):** reliable networks ensure accuracy of data delivery[15]. High reliability is essential in data sensitive applications such as remote health monitoring and other telemedicine applications. Equally, it is indispensable for Bitcoin or any other Blockchain application.
- **High security** ensures appropriate levels of authentication, authorization and accounting for each network user and it prevents and monitors unauthorized access. High Security networks are essential to protect confidential, secret and sensitive data from theft and alteration. Automated Living applications such as Intelligent Traffic Systems in Smart Cities or Smart grids, and applications such as e-banking, collaborative Telepresence or Virtual Social Interaction will require the highest levels of security and protection.

[13] Refer to the Communications Chambers report, chapter 5, page 24.
Available at https://www.libertyglobal.com/pdf/publicpolicy/Liberty-Global-Policy-Series-Connectivityfor-the-Gigabit-Society.pdf
[14] Cisco Global Cloud Index: Forecast and Methodology, 2015–2020
[15] expressed as the proportion of sent packets successfully delivered to the destination within the time constraint required by the service

4. ENHANCED NETWORKS ARE REQUIRED TO BUILD THE GIGAWORLD

Figure 6

QUALITY OF EXPERIENCE TRANSLATED INTO QUALITY OF SERVICE FEATURES

QoE	Network QoS	Definition	Applications
Perception of reality	High bandwidth	• Increasing bit-rate of **available or consumed information capacity**	• Cloud-enabled services, video services, connected things
Perception of instantaneity	Low and consistent latency	• **Reducing delay in data comm.** • **Equivalent levels** regardless of the used technology	• Real-time and instant data transmission (commands sharing or in M2M communications)
Assurance of accuracy	High reliability (packet loss and jitter)	• **Accuracy in data delivery,** proportion of sent packets successfully delivered	• Data-sensitive applications that are mainly life-critical or business-critical
Assurance of security	High security	• **Prevent unauthorizes access,** misuse, modification, or denial of network-accessible resources	• Protection of confidential, secret and sensitive data
Assurance of service continuity	High resilience (or availability)	• Ability to **provide and maintain an acceptable level** of service	• Functioning of real-time applications
Ubiquity	Coverage and mobility	• Ability to **provide similar network characteristics** in all locations and **seamless handed over** between access points and across networks	• On-the-move applications across technologies and geographies
Flexibility	Position accuracy & low energy cons	• Determination via the network – the device's positioning in 3D • Reducing energy consumption	• Use of position apps • IoT applications that contain sensors

Source: Arthur D. Little Analysis

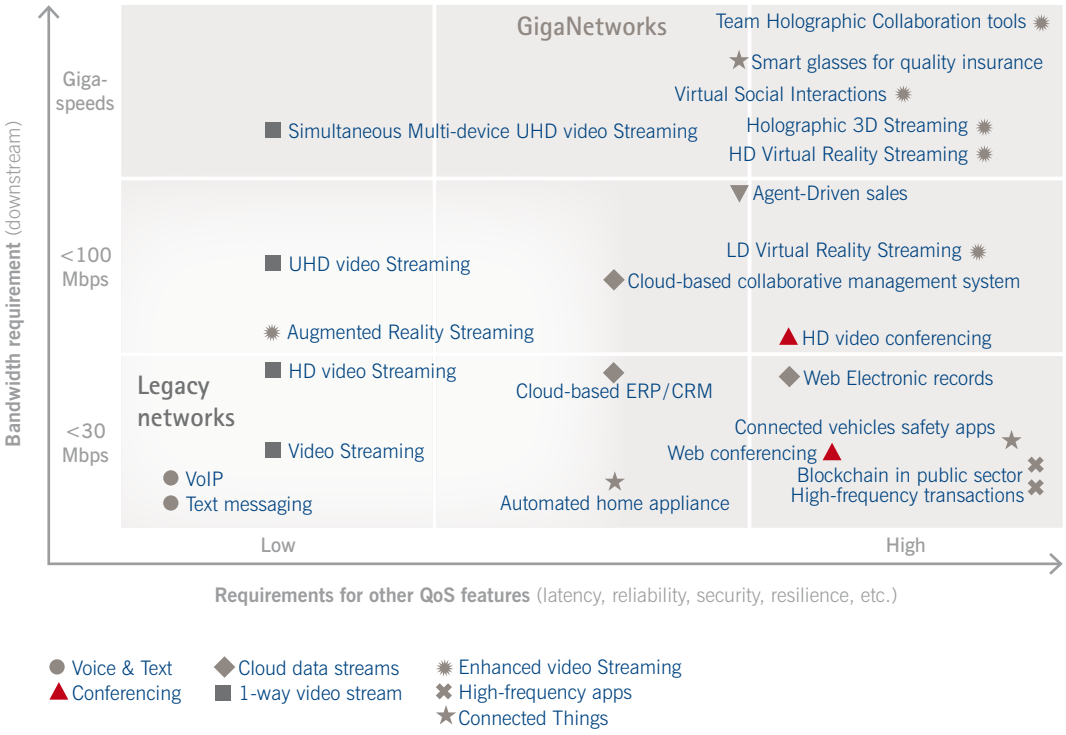
» **High resilience (or availability):** resilient networks are able to provide and maintain an acceptable level of services without interruptions. High resilience is critical for the functioning of real-time applications like patient health monitoring.

» **Coverage and Mobility:** Ubiquity is only secured if connectivity is provided in all locations relevant to the use case. Equally, many applications demand seamless handover between network access points and across networks. Mobility is also defined by the maximum speed at which a seamless hand-over of a defined QoS is performed.

» Finally, **position accuracy** (the ability to determine via the network the device's positioning in a threedimensional space) and the **energy consumption** of devices' batteries will also be critical for a range of use cases

Figure 7

SIMPLIFIED OVERVIEW OF NETWORK QUALITY OF SERVICE REQUIREMENTS



Source: Arthur D. Little Analysis

"GigaApps will drive a variety of use cases, requiring very different combinations and levels of enhancements to network QoS."

"Investment in bandwidth is only one element the GigaNetwork operators must invest in and make provision for."

4. ENHANCED NETWORKS ARE REQUIRED TO BUILD THE GIGAWORLD

4.3. Deployment of GigaNetworks will require substantial and continuous investments

As described in the previous section, the advent of GigaApps will push current GigaNetwork performance requirements to new levels. This will imply new network architectures to power new Quality of Experience levels.

Several network technologies, existing or under technical and operational development, can enable GigaNetworks[16]. They all share a large proportion of fiber technology; whether to the consumer premise (e.g. fiber-to-the-home or fiber-to-the-building) or for most part of it (e.g. fiber-DOCSIS networks deployed by cable operators or 5G with fiber-to-the-site backhaul). Their roadmaps already provide or foresee the possibility to meet the Quality of Service requirement of GigaApps and use cases.

GigaNetworks are being deployed in large parts of Europe, but they only cover some 33% of EU Member State households by end September of 2016[17]. Almost all network operators agree on the end-state picture, where GigaNetworks will be the standard. Substantial network investments are still required to cover the remaining households/buildings and all outdoor areas. That is not all: continuous investment will be required to keep the networks up to standard.

Rolling out advanced network technologies in the access network, the network part to which the consumer's device connects, will itself not be sufficient to deliver the required QoS. Investment in network management systems will also be required to manage the performance levels to be provided for each Quality of Service feature, according to the underlying use cases (overall investment to reach GigaNetworks are estimated to reach between € 500 billion and € 900 billion[18]).

Finally, the QoS performance level will also have to be managed in the core network, but more importantly at the IP interconnection level, i.e. where IP networks interconnect[19].

[16] Refers, among others, to the definition of the VHC networks by the European commission
[17] Source: IDATE FTTH/B Panorama, 2017.
[18] ADL research
[19] For more detail on such technologies and business models, please refer to our "The Future of the Internet" report (www.adl.com/FutureOfTheInternet)

NOTES

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New monetization models

5. NEW MONETIZATION MO

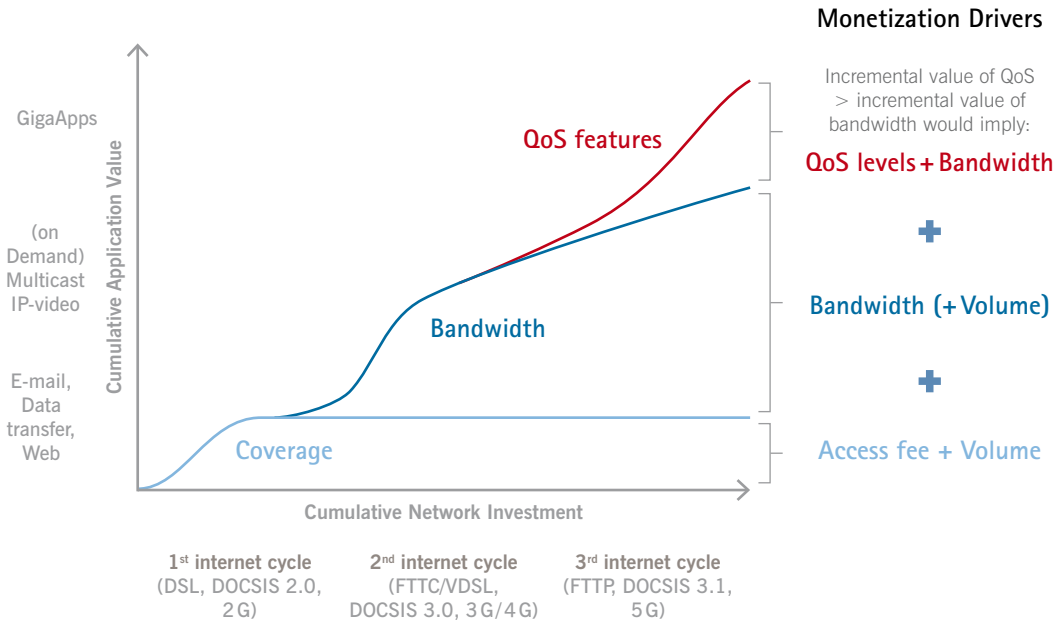
Introducing Quality of Experience/ Quality of Service in monetization models

For an individual GigaWorld application, the added-value of network investment will come from increased bandwidth or improved Quality of Service or both. Networks that do not deliver low latency and high accuracy of transmitted data will be unable to meet the Quality of Experience standards consumers will be willing to pay for.

Early improvements to Quality of Service levels will need to be monetized through new business models and pricing plans. Failure to do so will mean that bandwidth and volume remain the only revenue drivers, risking new investment being targeted only towards additional capacity and not to more and better Quality of Services features. In such a scenario, Quality of Service features will need to be part of network technology roadmaps. This will be a substantial contribution to making the GigaWorld innovation cycle function effectively.

Figure 8

GIGAWORLD NETWORK INVESTMENTS CALL FOR A NEW MONETIZATION MECHANISM REFLECTING THE INCREMENTAL VALUE OF QUALITY OF SERVICES FEATURES



Source: Arthur D. Little Analysis

DELS

New monetization models are necessary ...

Ensuring that Quality of Service improvements become a feature of new monetization models is not the only challenge that the emerging innovation cycle must confront. Gaining consumers' acceptance is of equal significance for the success of monetization models proposed by device manufacturers, application providers and network operators.

"New monetization models should reflect new value creation drivers – in particular QoS – which supplement current drivers such as access, volume and bandwidth."

Consider the following examples of models to monetize Quality of Service:

> **On demand QoS paid by the consumer.** A user wants to experience a live concert via holographic presence. He may want to have extra low latency and reliability for the duration of the event, and be willing to pay for on-demand, and scheduled enhanced QoS. Other users, for instance those living in advanced smart home environments or being very sensitive about security and confidentiality, may opt for a service that continuously provides increased QoS for one or more features (security, latency, resilience, etc.). Finally, some users may want additional QoS only for a selected group of applications, e.g. Telemedicine or e-Government services.

> **On demand QoS paid by the provider of the application or services.** A sales representative offers a person shopping for a fridge a holographic telepresence meeting in a virtual renovated kitchen. Virtually walking through the kitchen with his potential customer the salesperson can change the brand, model, or color of the fridge with a simple gesture, instantaneously providing the customer with additional information. The seller pays for the required extra QoS, as the marginal cost is limited and the customer would probably never go to the sales representative's showroom.

> **Multiple actors paying for the improved QoS.** A consumer considers installing a smart home surveillance solution enabled by a secure and resilient connection. This would improve his risk profile and his insurer would be willing to offer a discount on the home insurance, to incentivize the adoption of the surveillance solution. In most cases, the price reduction would outweigh the additional cost incurred by the consumer for additional QoS. Different monetization options can be envisaged: the discount on the insurance could be integrated in the surveillance solution or granted directly to the consumer. The QoS could be paid by either the consumer or the smart home solution provider.

These examples show that emerging QoS-based monetization models will take various forms according to:

» The intensity of usage: how much is consumed?
» The QoS features requested: which features and how are they provided?
» The underlying service relationship: who pays for what QoS feature?
» The price model: how much to pay and according to what metric?

5. NEW MONETIZATION MO

… and evolve as use cases spread and technology develops

It is impossible to forecast with any degree of accuracy, which monetization models will emerge and be accepted by consumers. In prior internet cycles, both the monetization of SMS and the pay-per-song model were unexpected. Nonetheless, in view of the case studies cited above we predict that the first wave of new monetization models will focus on stimulating adoption and simplifying the user experience. These monetization models focus on affordability and mitigate risks, like the so-called bill shock, e.g. through pay-per-use or freemium models to lower the threshold for early adoption. Over time, the consumer will better understand the value of GigaApps and their relationship to broadband connectivity. The market will then experiment with new monetization models to (i) avoid unnecessary complexity from overlapping use cases and (ii) to take into account the continuous network investment to enhance all QoS.

Figure 9

EVOLUTION OF QOE/QOS-BASED MONETIZATION MODELS



	Emergence of isolated use cases and monetization models	Increasing overlap between use cases and monetization models	Emergence of complex monetization models to keep user experience simple
GigaApps	Single use case	2–5 overlapping use cases	Large numger of use cases
QoE/QoS features covered*	Single set of feature	Addition of limited number of features*	Multiple sets merged into one
Involved Parties	User-pays or simple double-sided model		Multiple-sided model with 1 lead aggregator
Examples	• Continuous low latency for VR gaming (paid by user) • On-demand low latency for telepresence education sessions (paid by Unversity) • Accuracy & security for remote maintenance robots	• High reliability for multiple eHealth apps such as tele-monitoring, teleconsulation, telesurgery • Low latency and ubiquity for in-home and on-the-move Augmented Discovery and Virtual Telepresence GigaApps	• Advanced Smart Home solution covering security, energy management, Virtual Telepresence, etc. • Fully-integrated Mobility solution covering self-driving vehicles,smart traffic mgt, transport booking, etc.

* type of features covered (e.g. latency, packet loss, jitter, coverage, etc.), level of QoS (e.g. 5, 10, 20 milliseconds latency), continuous or demand provision, etc.

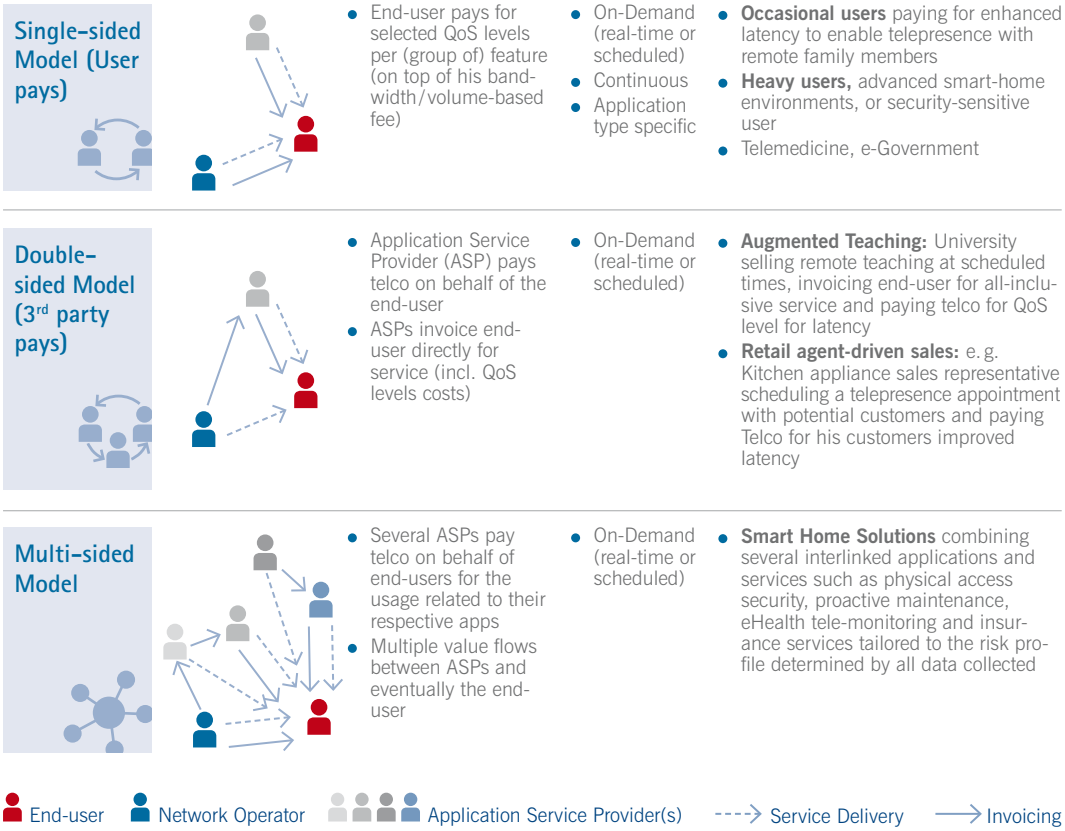
Source: Arthur D. Little Analysis

We anticipate that the predominant monetization model in the emerging GigaWorld will remain the flat fee, with service standard level for all quality of services features. However, exception-based pricing for QoS for more exclusive use cases - defined by content and by time-limited use - will become more prevalent over time.

As more complex monetization models are needed to ensure the user experience remains simple, one value-chain participant will likely take the role of lead aggregator with the mission to consolidate several use cases, the required set of QoE/QoS features and actors into easy to understand monetization models[20]. Application service providers, device manufacturers and network operators are expected to compete for this role. Their respective relevance and legitimacy for both the consumer and other stakeholders will be determined by the strength and attractiveness of a consumer offering. Eventually consumers will most probably make use of several lead aggregators

Figure 10

ILLUSTRATION OF MONETIZATION MODELS



Source: Arthur D. Little Analysis

[20] For instance, network operators played that role in the 2nd internet cycle by aggregating voice, internet and TV services

5. NEW MONETIZATION MO

for various services, for example:

- the network operator providing the optimal QoE/QoS package for all basic in-home use cases
- an Integrated Mobility Service provider covering all mobility use cases
- a device manufacturer specialized in connected devices for specific industrial use cases e.g. remotely controlled maintenance robots/drones
- an institute of learning providing educational services based on advanced virtual reality tools e.g. for highly-qualified technicians or health-care students

NETWORK VIRTUALIZATION WILL UNDERPIN NEW QUALITY OF SERVICE–BASED MONETIZATION MODELS

The emergence of GigaApps will require new "on demand" Quality of Service features. Today, bandwidth and coverage enhancements are controlled by physical changes to the network topology or supporting technologies e.g. a smart-phone or modem. Few bandwidth adjustments can be performed in near real-time with auto-mated processes.

However, the design evolution of GigaNetworks will drive major efficiencies in how QoS features are provisioned. Virtualization of networks through Network Functions Virtualization (NFV[21]) and Software Defined Networking (SDN[22]) will en-able networks to become programmable and automated. Programmable in the sense that the network can be customized and controlled through flexible interfaces; automated in the sense that the network can fulfill these requests without manual operations.

With SDN and NFV, operations that until now require lengthy implementation processes and physical network changes (with a higher risk of errors) will be executed at internet speed and scale[23]. We anticipate that GigaApps will also accelerate as a result of increased network virtualization strategies from major telecom infra-structure players.

[21] NFV leverages virtualization technology from the data-center environment to implement network functions as software components

[22] SDN provides dynamic interconnection of network functions (whether physical or virtual) and the associated service end-points

[23] See our report "Reshaping the future with NFV and SDN" (www.adl.com/NFVandSDN)

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Unlocking new market value

6. UNLOCKING NEW MARKET

6.1. GigaWorld policy: driving the emergence of an innovative ecosystem

GigaApps can unlock a new world, helping us to address key challenges in our societies. In addition to the societal benefits of improved and more sustainable mobility or healthcare, there is substantial value at stake, close to € 500 billion in Europe alone by 2025 (see section 6.2).

As discussed in chapter 2, all elements of the GigaWorld innovation cycle need to grow simultaneously. This supporting ecosystem is at the heart of potential game-changing GigaApp innovation.

The development of new devices and applications, investment in GigaNetworks and new monetization models form an innovation cycle that will create more value with each iteration. Over time, it will also ensure that innovation becomes available and more affordable for the mass-market.

Experimentation, failure and continuous realignment are critical elements of the cycle that need to be understood and nurtured. This is key to ensuring each stakeholder trusts the process, and invests in its collective success.

Incremental value will come from improved Quality of Services features offered by GigaNetworks. Moreover, new monetization models will be needed to accelerate investment and to distribute value between different stakeholders.

Policy and regulation have a positive role to play by removing potential hurdles in the virtuous cycle or optimizing its functioning. A forward looking and sustainable policy framework has the following characteristics.

Targeted incentives and removing barriers to entry

The role of regulation in the GigaWorld is to ensure that the innovation cycle functions well, iterates and creates value. Policies that accelerate digitization, stimulate innovation and uptake, and incentivize network investment will optimize the innovation cycle. Equally, policies should (continue to) ensure a fair distribution of value amongst all ecosystem stakeholders and correct abuses.

A holistic approach

Innovative GigaApps will increasingly be developed on the basis of large and interconnected ecosystems. Policies that attempt to regulate on the basis of static markets with clear boundaries (e.g. telecom mobile, telecom fixed, devices, applications, etc.) have for some time been under pressure from the emergence of over-the-top service providers. In the future, GigaNetworks will

increasingly interconnect with a broader range of industrial partners for instance healthcare, mobility, manufacturing and logistics. Device manufacturers, application developers, service providers and network operators will jointly shape new service offerings, new business models, new infrastructures and hence, new ecosystems. Traditional market boundaries will rapidly become obsolete and only policies that take a holistic approach to the ecosystem of the GigaWorld will be necessary.

Forward-looking and dynamic policy

In the GigaWorld, the pace of innovation will further accelerate and the timing of disruptions in technologies, services and consumer behaviors will largely be unpredictable. Static policies tied in the recent past will rapidly lose all relevance and be unable to address emerging hurdles in the innovation cycle. A forward-looking and dynamic policy is needed.

Figure 11

GIGAWORLD PARADIGM SHIFT ON POLICY-MAKING

1st and 2nd internet cycle Policy-making		GigaWorld: Driving the emergence of a new ecosystem
Innovation through promotion of competition	New ecosystem needs first to emerge	Stimulate digitalization & network investment Ensure fair distribution of value & correct abuses
Promotion of overall markets	Increased number of emerging markets with specific and different applications	Demand-side stimulation measures
Markets with clear boundaries	Convergence of sectors and increasing complexity of ecosystems' interconnections	Holistic ecosystem approach
Past/present focused and static	Increasing pace of innovation and unpredictable timing of disruptions	Forward-looking and dynamic

Source: Arthur D. Little Analysis

6. UNLOCKING NEW MARKET

"Forward-looking" policy is based on scenarios and refrains from premature intervention. "Dynamic" policies also stimulate market entry, innovation and the development of new business models. In this way, the innovation cycle is optimized.

Defining the GigaWorld ambition

Given that the emergence, pace and precise form of how the GigaWorld will evolve remains uncertain, it is impossible for policy-makers to predict which market players, technologies and supporting ecosystems will prevail. Therefore, their first task is to stimulate a process of testing and refinement to accept failure, and to encourage further iterations of the innovation cycle. Policies that attempt to prescribe an outcome, or define how the innovation cycle will function, will diminish future potential value creation.

But there is strong value in policy-makers establishing ambition: what should the GigaWorld bring to society? No other stakeholder is in a position to do so in an impartial way for the wider benefit of society. Setting targets, as the European Commission started to do in the recent years[24], is certainly a step in the right direction. However, the ambition should focus on the outcome to be delivered rather than the means of doing so.

6.2. GigaApps will unlock markets to the value of hundreds of billions of euros

Together, the three families of GigaApps will affect most economic sectors. Fundamentally, future GigaApps will generate value by:

- **Reducing barriers to innovation and time-to-market** for Small and Mid-sized Enterprises (SMEs) and Small Offices and Home Offices (SoHo) which will be enabled to affordably access online service capabilities which currently are only available to larger enterprises or niche businesses. Examples include access to cloud-based advanced analytics (e.g. data mining and online analytical processing to understand customers' habits), and access to shared platforms to reach new markets (e.g. shared physical point of sales where several SMEs are present as hologram projections).
- **Increasing productivity** through increased automation of tasks, leading to faster manufacturing processes and production, e.g. AR-assisted installation of solar electricity generators, or robots autonomously building houses.
- **Unlocking new services** by enhancing interactions between people and their surroundings via unprecedented experiences, e.g. virtual social interactions and AR guidance for tourism.

[24] E.g., Digital Agenda under Europe 2020 strategy setting minimum access speed at 30Mbps and half of the households a subscription at 100Mbps. Later, the 2025 ambition set under the Digital Single Market strategy raised the connectivity speed target to 100Mbps for all European households

We foresee that the industrial manufacturing, engineering, logistics and automotive sectors will benefit most from the three families of GigaApps, accounting for close to 25% of total unlocked value, or close to €≈110 billion in Europe by 2025. The smart home and entertainment sectors, in addition to the retail and e-commerce come next, accounting respectively for 14% and 16% of the overall GigaWorld market, followed closely by the healthcare and travel and tourism sectors.

"The unlocked value creation is forecasted to reach €450-500 billion per year by 2025 in Europe (base case)."

We anticipate that Augmented Discovery and Virtual Telepresence services will largely enable use cases in the industrial sector (e.g. collaborative prototyping, drone-controlled warehouse management), the smart home & entertainment sector (e.g. holographic projection of movies or sport events, virtual teleconferencing, AR-assisted of Do-It-Yourself installation of kitchens), and the retail & e-commerce sectors (e.g. virtual sales agent). Automated Living related applications, on the other hand, are expected to be present in all sectors, as connected objects and machines are increasingly deployed in all kind of situations.

By 2025, Automated Living is expected to profoundly disrupt all industries. Its applications will enable not only human-to-machine interactions but also machine-to-machine[25]. Exploiting a broad variety of already deployed sensors and devices will enable widespread adoption and development of a large number of use cases.

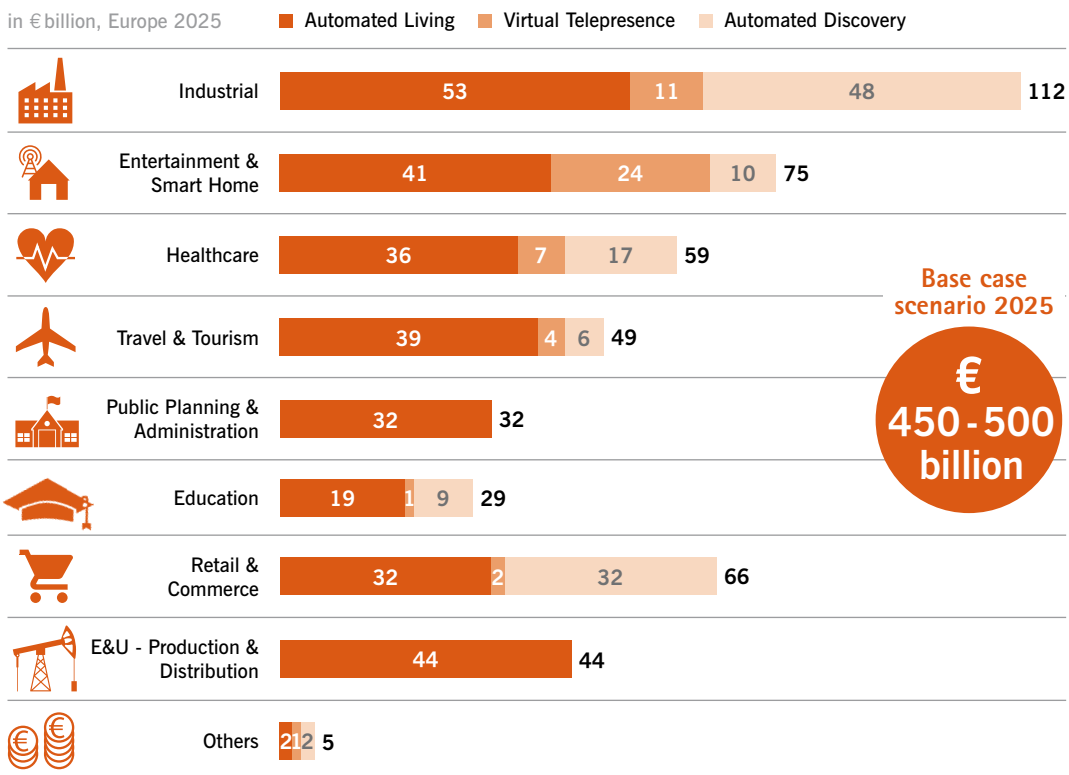
Together, the three families of GigaApps should unlock markets estimated at €450-500 billion per year in Europe by 2025 (and yearly €2.4-2.5 trillion at global level). Augmented Discovery and Virtual Telepresence are forecasted to grow at an annual growth rate (CAGR) of 67% and 68% respectively while rather Automated Living should grow at a pace of 19% over the same 2016-2025 period.

[25] closed loop communications between machines to optimize manufacturing process e.g. sensors informing a learning artificial intelligence unit in charge of maintenance tasks

6. UNLOCKING NEW MARKET

Figure 12

MARKET SIZE FORECASTS FOR GIGAAPPS PER SECTOR – BASE CASE – EUROPE



Source: Arthur D. Little Analysis

INDUSTRIAL: Engineering, Manufacturing, Logistics and supply chain management, Real Estate, Automotive, Military and Defense

SMART HOME & ENTERTAINMENT: Smart Home, Gaming, Music, Video and Sports

HEALTHCARE: Medical and Wellness

TRAVEL & TOURISM: Travel, Transportation and Tourism

PUBLIC PLANNING & ADMINISTRATION (PPA) including urban environments

EDUCATION & TRAINING including 3D and holographic learning and virtual classrooms

RETAIL & COMMERCE: e-commerce and shopping and Marketing & Advertising

ENERGY & UTILITIES - PRODUCTION, DISTRIBUTION: Energy management, Utilities but excluding smart energy initiatives (under PPA)

European GigaWorld markets are expected to grow at an average annual rate (CAGR) of 22-27% thanks to the relative maturity of its digital market and networks, and the significant Augmented Reality and Virtual Reality device adoption rate already visible in some countries.

The Americas region (mainly driven by North America) should grow at a CAGR of 18-25%. In particular, North America has the highest awareness, adoption, use and monetization of the latest technologies and invests massively in its digitization. Asia-Pacific, for its part, should be growing at a slightly slower rate of CAGR of 15-24%.

The growth of the European market is derived largely from an accelerated digital transformation of traditional industries (i.e. manufacturing, automotive and transportation) and by favorable government support[26]. Globally, the Asia-Pacific region is expected to become the largest GigaWorld market, reaching a size of € 1.1-1.2 trillion in 2025. The APAC dynamic is driven by increased investment in new infrastructures, modernization of local small and medium-sized businesses adopting IoT (China, India, and Philippines) and the numerous initiatives to develop new smart cities. The Americas (mainly the United States and Canada) should reach a market of € 0.9-1 trillion, driven by rapid growth of IoT, mainly in industrial and healthcare sectors.

These forecasts should be read as the most likely take-up scenario for GigaApps. However, a number of factors could affect the value creation potential, ranging from a low case of € 250 billion to an out-perform market size of 660 billion per year in Europe by 2025 (and yearly € 1.3-3.5 trillion at global level):

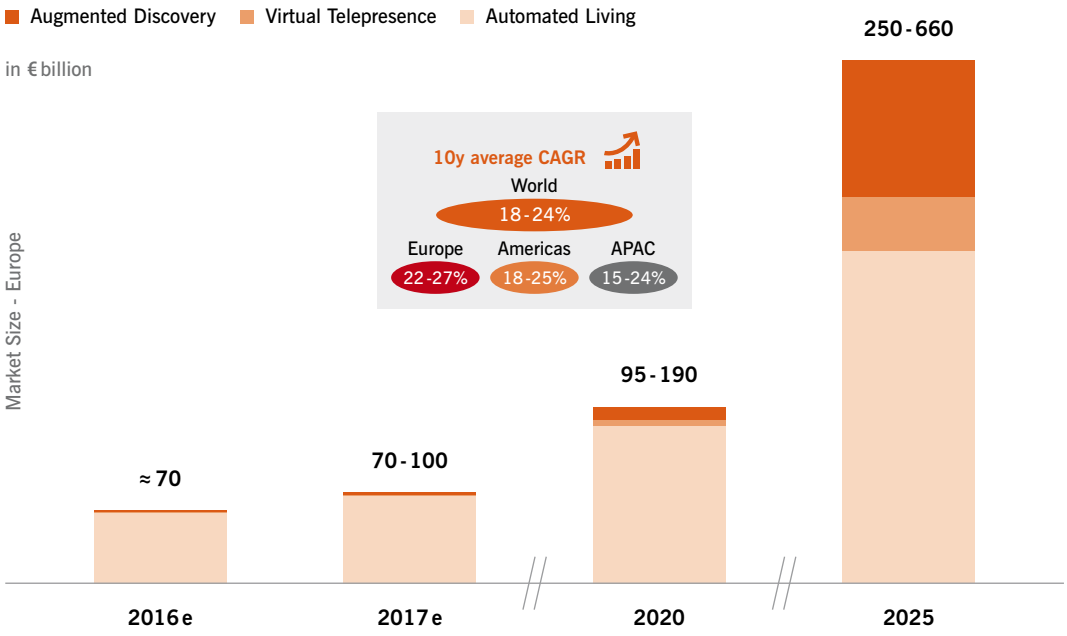
- **Commonality in device usage:** the use of similar devices by several applications leads to larger markets as the barriers to entry to a particular application (e.g. cost of the device required to enable to application) are distributed among all the used applications; e.g. today's smartphones can enable thousands of applications, creating major synergies.
- **Government support** through a public administration at the forefront of adoption of GigaApps, through measures such as the active promotion of device or application. A good example would be Public Authorities that take the lead in smart cities initiatives[27].
- **Availability of GigaNetworks** to enable GigaApps and hence provide required coverage, bandwidth and QoS features.
- **Predominant use of monetization models that foster adoption:** for instance, an application launched with a freemium model has more chance to be adopted than an application where all its costs are borne by the consumer.

[26] E.g., initiatives such as the European Union 7th Framework Programme for Research and Technology Development and Europe's Horizon 2020 fund research and innovations in projects related to IoT.
[27] e.g. Stockholm, Dubaï, Vienna, Valencia, Dallas

6. UNLOCKING NEW MARKET

Figure 13

ESTIMATED MARKET SIZE FOR GIGAWORLD APPS – EUROPE



Take-up scenario drivers

Use of devices

Commonality in the use of devices that endorses synergies between use cases

Public support

Governments' support and promotion that **incentivize** the adoption of devices and/or of applications

GigaNetworks

Adoption of networks that **enable** GigaApps

Monetization models

Predominant use of monetization models that **foster adoption rates**

Source: Arthur D. Little Analysis

The level of alignment achieved by the GigaWorld innovation cycle explains the differences between our base case forecast estimates and the low- and the out-perform scenarios.

Our base case scenario assumes that there will be around 18 billion connected objects by 2025. The adoption of augmented reality and virtual reality technologies and devices is assumed to reach close to 25% of the population. The base case scenario also foresees around 550 smart cities in the world, while close to 70% of population would have access to GigaNetworks.

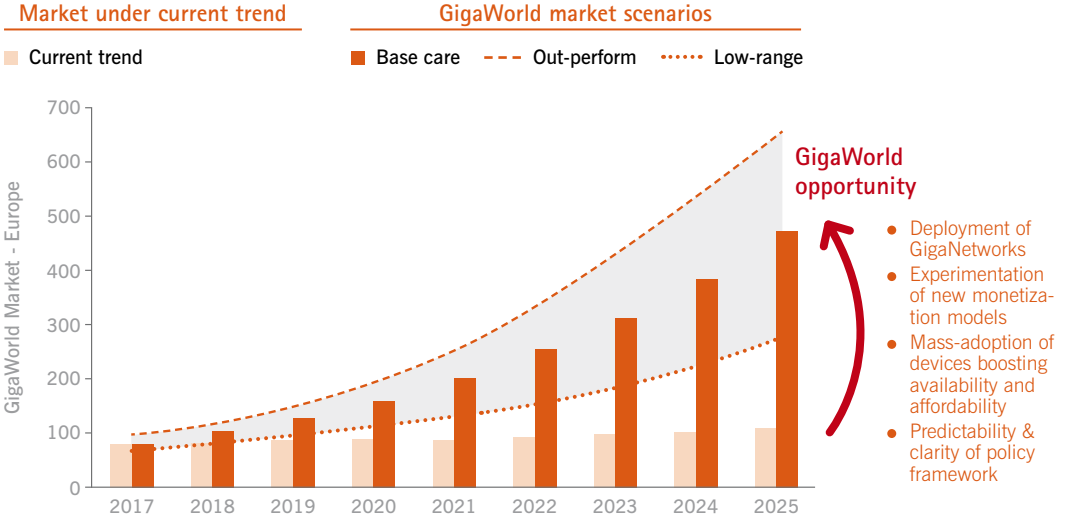
The out-perform scenario assumes that the virtuous cycle functions effectively and most people have access to GigaNetworks (i.e. more than 90% of population). The number of connected objects would reach 30 billion by 2025 and around one third of consumers would use next-generation devices powered by augmented and virtual reality technologies. Globally, more than 600 smart cities and regions would act as permanent incubators for new applications and use cases.

The low-range scenario is based on a sub-optimal function of the GigaWorld innovation cycle as uncertainties in policies, network deployment and monetization models inhibit the take-up of the GigaWorld. It would translate into a scenario with only 12 billion connected devices by 2025, an adoption rate of AR/VR devices of 15%, with close to 400 - 450 smart city initiatives worldwide. In this scenario, GigaNetworks would reach only 60% of population. Still, this low-range scenario assumes an overall efficiently running GigaWorld innovation cycle.

However, should no action be undertaken to enable and optimize the GigaWorld innovation cycle, today's existing 2nd internet cycle would be unable to unlock the substantial new market values we predict.

Figure 14

GIGAWORLD MARKET OPPORTUNITY



Source: Arthur D. Little Analysis

6. UNLOCKING NEW MARKET

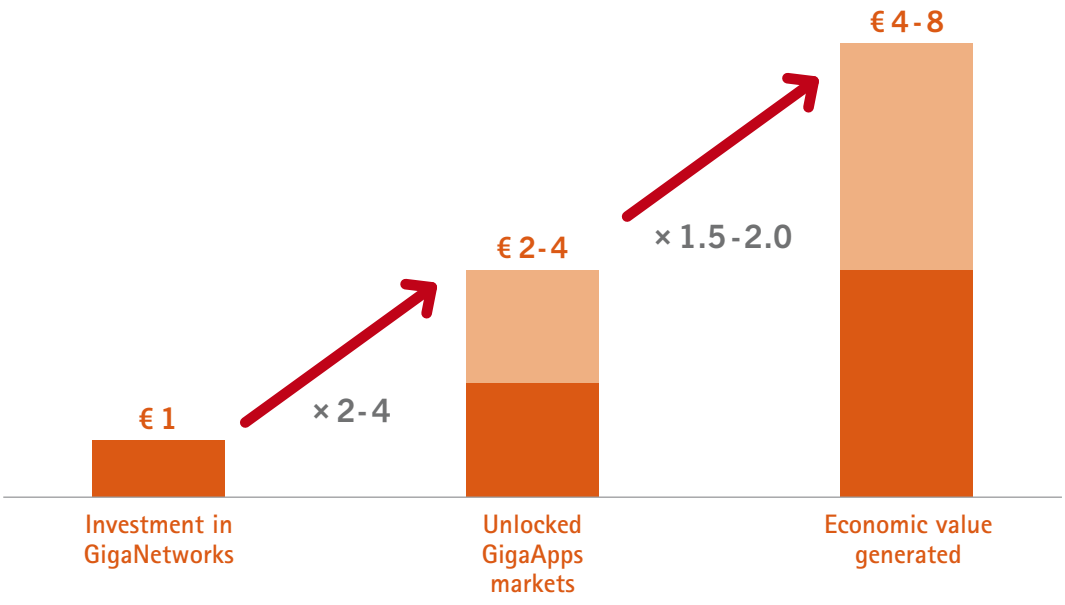
The absence of network services and monetization models based on QoE/QoS, uncertainty of regulation stimulating the incentive to invest, and an inflexible approach would mean the emergence of the GigaWorld will be delayed - at best[28].

Enabling the GigaWorld innovation cycle will have substantially more benefits than purely unlocking new market value. We anticipate that indirect employment, economic growth and improved health benefits will rapidly accrue, translating into substantial improvements to countries' economies, measured in GDP.

Our analysis indicates that each euro invested in GigaNetworks generates € 2 to 4 of market value from GigaApps. In addition, each Euro of market value translates into roughly € 1.5 to 2.0 in GDP. Therefore, each Euro invested in GigaNetworks is expected to unlock around € 4 to 8 of benefit to the overall economy.

Figure 15

ESTIMATED ECONOMIC IMPACT OF EVERY EURO INVESTED IN GIGANETWORKS



Source: Arthur D. Little Analysis

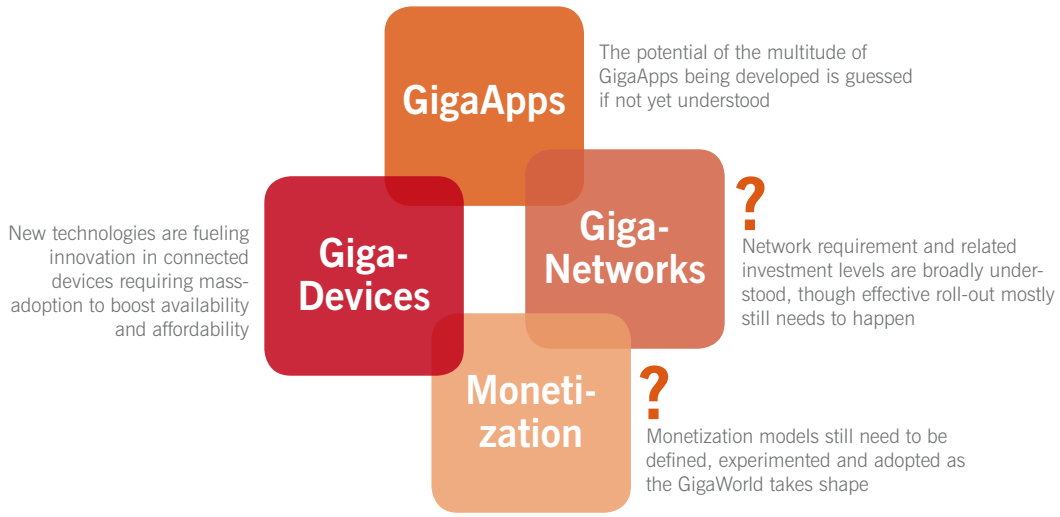
[28] At the current pace, estimated forecast by 2025 range from 5 to 10 billion connected objects, 5-10% adoption rate of AR/VR enabled devices, fewer than 250 smart cities initiatives launched and GigaNetworks coverage reaching between 35 and 50% of population.

In conclusion:

- The GigaWorld could mean a promising future for our society, with substantial benefits coming from a new wave of innovation.
- The inability to efficiently launch the GigaWorld innovation cycle will represent a major opportunity cost in terms of market development of € 150 - 560 billion per year by 2025 in Europe or € 0.7 - 3.1 trillion per year at global level.
- Device manufacturers, GigaApps service providers and GigaNetworks operators must have the room to experiment and to compete in order to unlock the GigaWorld's potential value.
- The development of GigaApps and innovative devices is already a dynamic sector. Besides, the required GigaNetwork investments and deployments are mostly well understood.
- That said, predictability and clarity of the public policy framework will be essential for all actors to invest further in the GigaWorld and to experiment with new business models.
- In particular, a high degree of flexibility and experimentation will be required for new monetization models to emerge and fairly distribute the generated value between actors and with consumers.

Figure 16

READINESS OF THE GIGAWORLD INNOVATIVE CYCLE



Source: Arthur D. Little Analysis

GLOSSARY

Abbreviation	Definition
4K	Horizontal resolution on the order of 4,000 pixels
5G	5G new radio
8K	Horizontal resolution on the order of 8,000 pixels
AND	Application Delivery Network
AI	Artificial Intelligence
AR	Augmented Reality
CCTV	Closed-circuit television
DOCSIS	Data Over Cable Service Interface Specification
DVB-H	Digital Video Broadcasting - Handheld
Gbps	Gigabit per second (1 Gigabit = 1,000 Mb =1,000,000 Kb)
GDP	Gross Domestic Product
HMD	Head-Mounted-Device
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
ISP	Internet Service Provider
KPI	Key Performance Indicator
M2M	Machine-to-Machine
Mbps	Megabit per second (1 Megabit = 1,000 Kb)
MBB	Mobile Broadband
NFV	Network Functions Virtualization
OTT	VoD Over-The-Top Video-On-Demand
QoE	Quality of Experience
QoS	Quality of Service
SDN	Software Defined Networking
SLAM	Simultaneous Localization and Mapping
SME	Small and Medium
SoHo	Small Offices and Home Offices
TCP/IP	Transmission Control Protocol/Internet Protocol
TGV	Train à Grande Vitesse
VR	Virtual Reality

NOTES

NOTES

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Liberty Global commissioned Arthur D. Little to author a study on the topic of GigaApps in a GigaWorld. The objective of this work is to contribute to a debate currently high on the agenda of industry, policy and regulation with objective analysis of the key trends, empirical evidence and a holistic perspective. The study reflects Arthur D. Little's thoughts on the topic of the emergence of the GigaWorld and the related paradigm shift, supported by industry analyses as well as case studies and company examples based on publicly available information. The study provides a basis for discussion for key stakeholders across public and private sectors on a broad set of topics related to development of new innovative ecosystems driven by next-generation applications and networks, and future strategic, policy and regulatory priorities.

Arthur D. Little

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